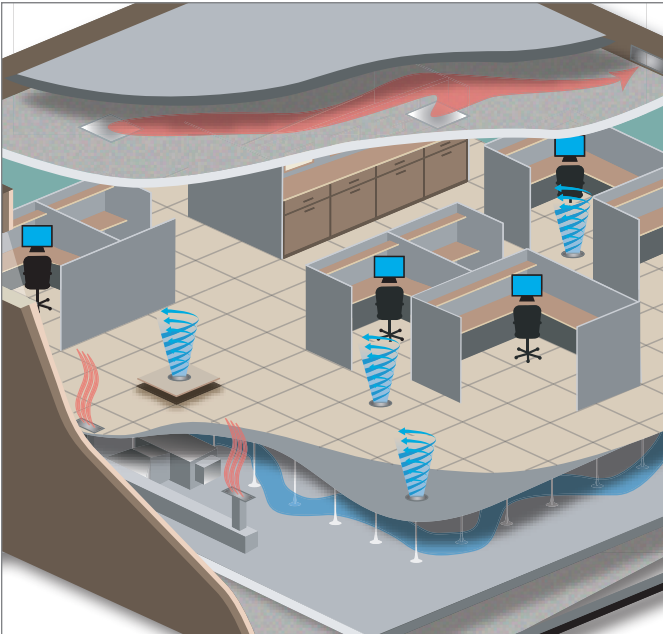


Introduction

Changes in office space usage, sustainable design, and indoor air quality issues have sparked considerable interest in the application of supplying conditioned air through a pressurized floor plenum. First used in computer rooms, underfloor systems allowed plenty of open space to both run cabling and supply large quantities of cool air under the intense heat of the electronics. Today, however, underfloor systems have found new markets in the open plan office. Several factors have led to this new application.

UNDERFLOOR AIR DELIVERY



Reduced Life Cycle Cost

A large open floor plenum provides space to run a large amount of cable for power and communications. A major change in offices over the last fifteen years has been the ever-growing need for voice, data, and power connections to every workstation.

When coupled with an open-plan office design and a trend towards a cross-functional organization, an office employee may experience a move as often as every six months. This type of movement is often referred to as churn.

The cost associated with churn as well as cabling moves are one of the largest costs an owner/tenant may face. A system that reduces the costs associated with churn moves may help reduce the total system life cycle cost. Raised flooring allows a lower cable move cost with the added benefit of a simplified HVAC move.

There may be tax advantages, as floor components may be considered as furniture and depreciated at a significantly faster rate than conventional HVAC systems.

Improved Comfort

Underfloor air distribution (UFAD) utilizes the principle of warm air rising from space loads. BOMA (Building Owners and Managers Association) reported that thermal and indoor air quality concerns were two of the top concerns and least met expectations of tenants. Traditional overhead air distribution systems are designed to do a very good job of mixing the air in the space and prevent stratification in the room. Applying the warm air rising principle, air may be provided below the occupants and discharged directly into the breathing zone at a relatively low velocity. People warm the air, so by natural convection, the air rises toward the ceiling. Since people only breathe the air in a zone from approximately the floor to 6', the space above this zone may be treated as a stratified air layer and the load components in this zone are treated differently.

Air provided by underfloor systems may be supplied at a low pressure, without ducts, which often reduces the energy to maintain space conditioning. The ventilation air is provided in the zone where it is most needed and moves pollutants upward, by the rising heated air, toward the return. Additionally, individually adjustable diffusers may result in an actual or perceived improvement in thermal comfort. The result is a system that may offer better ventilation and indoor air quality that is also more energy efficient and comfortable than a traditional overhead supply system.

The system designer must view the application of an underfloor air distribution system very differently. Special consideration must be given throughout the design process from design schematic stage, to load estimate, to commissioning.

System Benefits without Special Air-Handling

While several types of underfloor system designs exist, this application guide covers a system offered by Krueger. The Krueger design utilizes standard air handling equipment and duct supply temperatures, which allows the system to also handle spot cooling requirements often found on every project. It avoids humidity control issues found in systems with higher air handler discharge temperatures. The air is distributed in the space through a pressurized plenum with helical floor diffusers. The plenum is supplied through a zone parallel fan powered "air column" terminal to modulate temperature and control plenum pressure. The terminal's controls mix primary and return air to maintain temperature in the space as well as maintain the desired underfloor pressure in relatively small zones. Heating and cooling requirements of specialized high load spaces and perimeter zones can be handled with a combination of conventional overhead systems and underfloor fan terminal units.

Basic Concepts

Basic Concepts

Underfloor air distribution systems use the floor space between the structural floor and the raised floor as a supply air plenum. Three concepts are normally associated with underfloor cooling, each with distinctive characteristics.

- 1) Displacement ventilation discharges air horizontally at the floor at very low velocities and near laminar flow conditions, and at small room/discharge temperature differences (Δt). The system uses the buoyancy effects, created by local loads, to attract cooler air at the floor and create a stratification layer above the controlled zone that is not mixed. While this provides excellent ventilation effectiveness in the occupied zone, it is not always the optimum solution for thermal comfort due to the potential for excessive vertical temperature variance, greater than the ASHRAE accepted 3°R to 5°R ΔT vertical stratification from head to toe. Additionally, limitations in supply rate (to avoid drafts) and temperature difference (to avoid cold feet) may limit the load capacity, such that overhead chilled ceiling panels or beams are often applied (with inherent humidity control issues).
- 2) The UFAD approach uses the same buoyancy principles as displacement ventilation. However, the air is discharged into the space with an adequate velocity and air pattern to provide mixing only within the occupied zone. The system is designed to maintain the stagnant zone above the breathing zone and provide a more uniform temperature variation in the occupied zone to keep it within the comfort envelope.
- 3) Known as Task Ambient Conditioning, airflow is typically provided from an underfloor system which is controlled at the workstation and is normally accomplished with a small fan that directs an air jet towards the occupant.

We will use the UFAD approach in this manual. There are two methods of utilizing an underfloor plenum to supply conditioned air to a given space. Either the entire plenum space is set to a relatively low pressure, approximately $0.10''\text{WG}$, or air is discharged into the plenum at a neutral (zero) pressure. With a neutral plenum, fans near the outlets draw the supply air from

the plenum and discharge it to the space or ducts supply each diffuser from a central source. Neutral pressure plenums have a reduction of leakage around floor tiles and plenum penetrations, but fan wiring, ducting, and energy costs may negate some of the system's inherent benefits. A pressurized plenum is easier to modify during use, but more care must be given to preserve pressure integrity. The Krueger system employs a pressurized plenum.

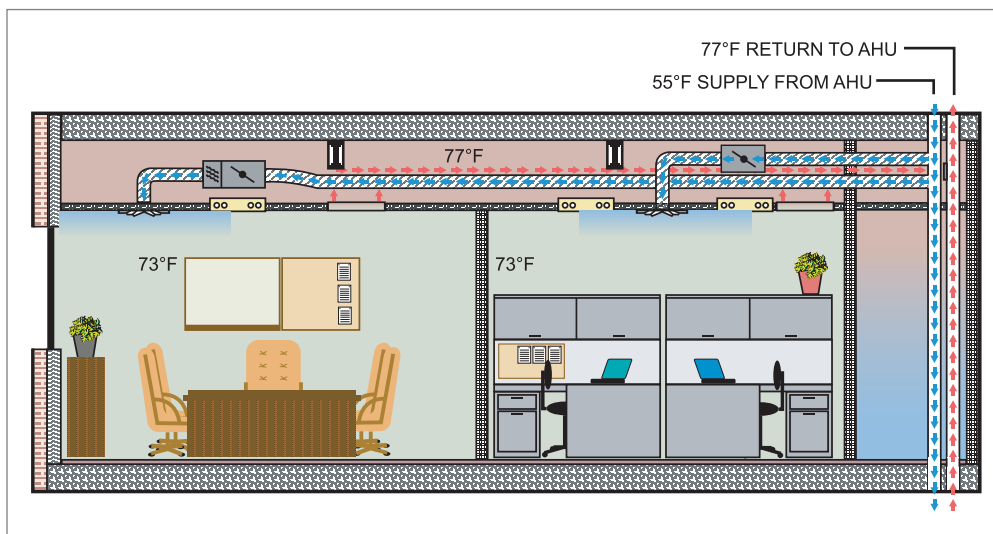
Using UFAD systems, conditioned air is brought in at floor level with occupant comfort limitations on how cold it can be supplied. The air must be provided at a warmer temperature than normal air conditioning levels, typically no colder than 61°F . Both equipment selection and operation as well as air distribution device selections are impacted. The large surface area and mass of the structural slab provide both a thermal mass that may shift load patterns and create thermal decay to diffusers located far from the point at which supply air enters the plenum. The space return air is removed near the ceiling and the entire volume returned to the air-handler.

Heating along the perimeter also presents challenges for UFAD systems. A number of separate units are typically provided, which control heating demands along the perimeter. Often, a booster fan terminal unit is placed under the floor near the perimeter, which contains a heating coil (electric or hot water) that is controlled to overcome transmission losses.

Two types of air handlers are typically employed with UFAD systems.

- 1) A special (and somewhat more expensive custom) air-handler is required to supply 61°F air at a dew point of 55°F .
- 2) A more conventional 55°F air handler is used in conjunction with an "air column" located near the space which draws a portion of the return air near the ceiling and mixes it with the supply air to maintain the floor plenum pressure and temperature.

CONVENTIONAL OVERHEAD AIR DELIVERY



UNDERFLOOR PRODUCTS ENGINEERING

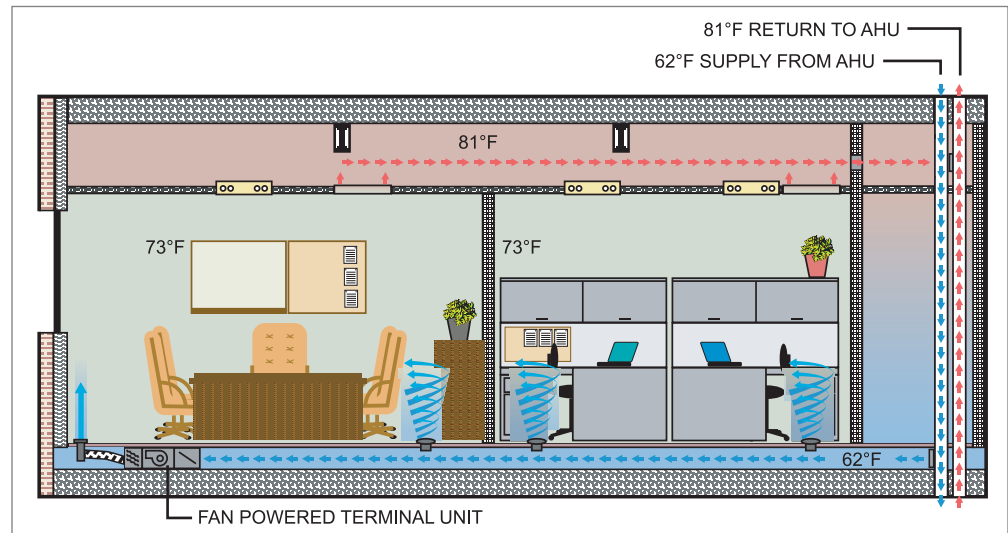
Basic Concepts

Many “third generation” HVAC systems employ Dedicated Outside Air Systems (DOAS). The use of a DOAS configuration makes great sense with UFAD systems, as it relieves the task of humidity control from the air handler, and increases system flexibility during part load operation.

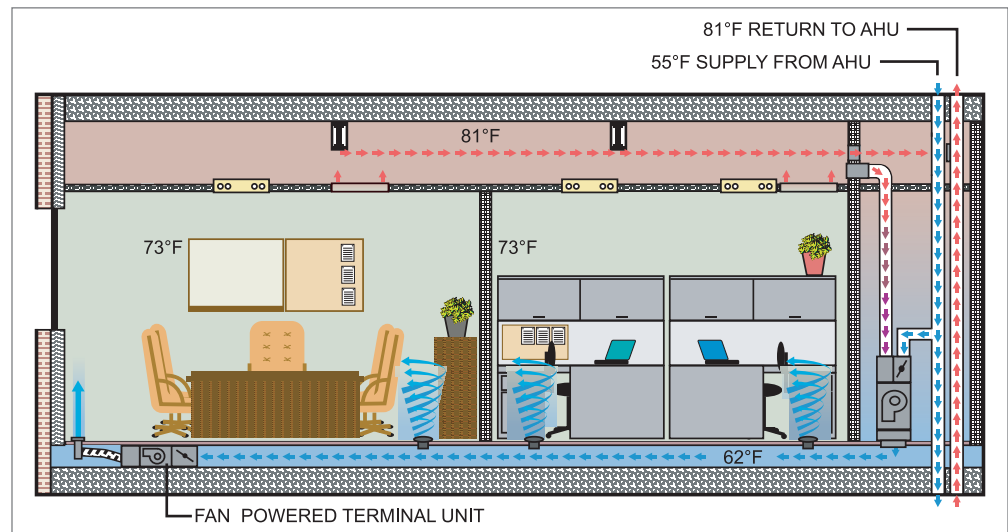
The Krueger system discussed here employs a method (shown in the second illustration), using a mixing unit and a conventional air handling unit (AHU). The specially configured parallel mixing Air Column VAV terminal uses variable fan speed to control underfloor air temperature and variable cold primary air to maintain desired underfloor pressures.

Spaces with high cooling demand, such as perimeter zones and conference rooms, present interesting challenges. To provide for these spot cooling situations, a fan powered terminal is provided under the floor to increase airflow. These spaces may have air requirements that cannot be handled by 65°F air without causing air distribution problems. When 55°F main supply air is used, the system may utilize ducted cold air underfloor, delivered to spot load locations, or traditional methods with overhead air distribution, such as VAV reheat or fan terminal units. Downward nozzles may be particularly effective, conditioning only the area immediately at the perimeter (shown in the bottom illustration).

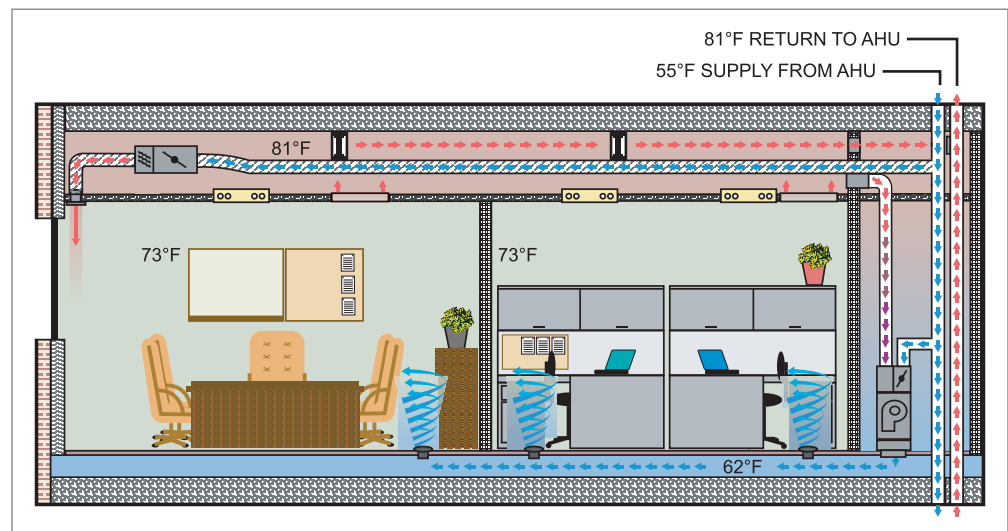
UNDERFLOOR SUPPLY FROM CUSTOM AHU



UNDERFLOOR SUPPLY WITH KUFM MIXING UNIT AND CONVENTIONAL AHU



UTILIZED COLD AIR FROM CONVENTIONAL AHU



Product Overview

Product Overview

Floor Plenum

The floor plenum resides in the space between the raised floor and the structural floor. 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, duct work is run through the space to special variable load areas, which may need partitioning for life safety or thermal zoning. Typical plenum depths range from 12" - 20", but a minimum plenum depth of 16" is suggested for Krueger products.

Diffusers

Room air distribution is accomplished through one of two types of floor diffusers. Interior spaces are controlled through a system of adjustable floor mounted diffusers, the Krueger FPD-R/FPDFR-R. Each diffuser consists of curved slots resulting in a helical air pattern and is located in an adjustable flow-rate mounting basket that is mounted through a hole cut in the concrete floor panel. The basket catches any dirt or spilled liquids and prevents contamination of the space below the floor. The adjustable basket/damper allows the occupants to adjust their diffusers to a comfortable level in their space. The diffuser can be adjusted manually or with a proportional actuator. The actuator can be controlled by a room mounted thermostat or connected to a building management system. The diffusers are designed to achieve mixing of the moderately cool underfloor supply air within a tight radius of the diffuser, at a low velocity. Diffuser airflow is about 70 - 110 CFM per diffuser. Two materials are available, standard (FPD-R) and fire rated (FPDFR-R).

A second type of diffuser, a linear bar-type (1850) is used with underfloor mixing VAV terminal units and perimeter booster fan terminal units. Both 0° and 15° deflection blades are available. This rectangular grille is used to provide an air curtain that washes exterior surfaces with warm or cold air and supplies higher air quantities than the helical interior zone diffusers. Various arrangements are used to match the airflow requirements of mixing VAV terminal units or booster fan terminal units. With the addition of a ducted plenum (FPD-D) or a damper actuator (FPD-V), one may provide variable volume control to selected spaces.

If desired, a linear bar type (1850) grille may also be used to allow return air from above the floor back to the underfloor mixing VAV terminal units utilizing a special heating/cooling changeover plenum (FPD-HC).

Underfloor Series Fan Powered Mixing VAV Terminal Units (KUFS - 10 1/2" & 14 1/8" Heights)

These low profile units are designed to fit under the floor, in the space between pedestals and the grids of the raised flooring system. Sizes range from 280 CFM to 1200 CFM. They are used for perimeter spaces, conference rooms, and other spaces with highly variable load patterns. They typically use a mix of supply air from both the floor plenum and ducted air from a floor diffuser which may increase the volume delivered to the room to meet the variable needs. The same style unit may be used with ducted primary air, when required, to meet higher thermal load requirements. Heating may be provided with either hot water coils or with electric heaters.

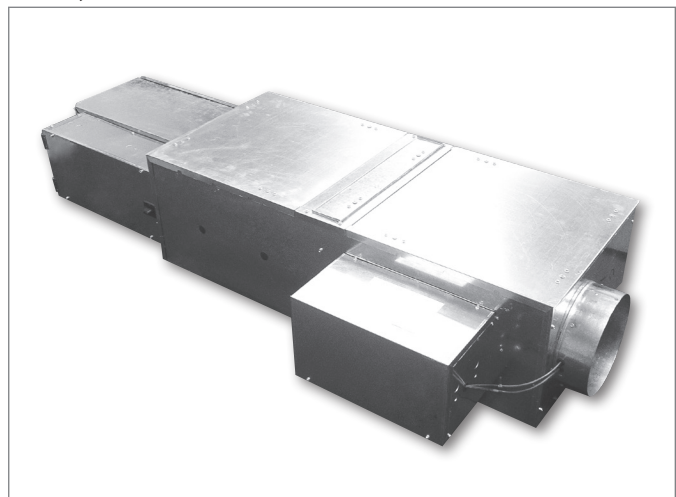
FPD-R, UNDERFLOOR HELICAL DIFFUSER



FPD-D, UNDERFLOOR PLENUM



KUFS, UNDERFLOOR SERIES FAN TERMINAL UNIT



Product Overview
KBF, UNDERFLOOR BOOSTER FAN TERMINAL UNIT

Underfloor Booster Fan Terminal Unit (KBF - 10", 14" & 16" Heights)

These booster fan terminal units are another option to handle spaces with variable load patterns and are well suited to address heating requirements of perimeter zones. Available sizes range from 325 to 2800 CFM. These booster fan terminal units also fit under the floor in the space between pedestals and the grids of the raised flooring system. Heating is provided in these with either a hot water coil or an electric heater. Additionally, they may be used to boost the quantity of underfloor air to more critical, higher load interior spaces.

Fan Powered Zone-Mixing VAV Terminal Unit "Air Column" (KUFM)

This unit mixes return and primary air above the floor and directs the mixed airstream under the floor. One unit is used per plenum zone and is mounted in a closet or utility space. The product is composed of a parallel fan powered unit that controls the temperature and pressure of the zone. The units use standard 55°F supply air from the air handler and blend the air with return air from the zone to provide (approximately) 63°F discharge air required in the plenum. The ECM motor in the unit varies speed, as required, to control the plenum temperature by varying the amount of recirculated air introduced into the plenum, while the primary air damper simultaneously maintains the plenum pressure by controlling the amount of primary air introduced into the plenum at approximately 0.06" WG.

KUFM, FAN POWERED ZONE-MIXING TERMINAL UNIT

Central Equipment Issues

Since Krueger's system uses a zone mixing/air column concept where primary air is supplied at normal unit design conditions, special air-handling equipment is not required. The system may be used with chilled water or DX air-handlers, or it may be used with many types of packaged equipment as well. Careful selection of coil entering air conditions will ensure that the required leaving air conditions are proper for each project, due to what may be higher than normal entering sensible heat factors. Part load operating conditions should be evaluated to be sure room humidity levels are maintained below 60% RH. Economizer should be used with all system types, where local climate permits, and should use an integrated differential enthalpy type. Due to low static pressure requirements, fan sizes may be lower than conventional overhead systems. When varying the volume to the zones, the use of a variable frequency drive is recommended to boost energy efficiency performance. Additionally, the use of good filtration is recommended since a prime consideration of the UFAD system is good indoor air quality.

Applicable Types of Buildings & System Pros and Cons**APPLICATION**

The total installed cost of an underfloor system is often equal to or greater than conventional overhead distribution and is not the answer to every building. However, underfloor air systems may represent life cycle cost savings when applied to the appropriate buildings.

First, UFAD may be applied in new construction office spaces where frequent churns are anticipated. Open plan construction normally allows for the best application. Owners will benefit from the reduced cost of moving offices, particularly the cost of communications cable and wiring. There may be depreciation tax advantages associated with UFAD systems. However, small spaces within a building are not well suited to underfloor air systems, nor are spaces with high perimeter to interior ratios or highly variable loads.

The second application is in retrofit situations, where the building characteristics make overhead air distribution systems difficult to apply. Recent trends to rehabilitate old warehouse space into offices and downtown revitalization of existing structures may fall into this category. The issues with elevator and plumbing fixture connections must be addressed. However, the savings and ease of providing the cabling services and air distribution under the floor may well pay for the cost of raised flooring. Also, the benefits of improved thermal comfort and indoor air quality may make the space even more attractive to tenants.

A third area where UFAD may make sense is in buildings with a very high ceiling and no place to run overhead air distribution. Some places of assembly fit into this category. Again, open plan and internal load concentration are the keys to successful applications.

SYSTEM PROS (+) AND CONS (-)

(+) Thermal Comfort: Since UFAD systems allow the occupant a degree of control over his own individual climate through adjustable diffusers, there is a greater degree of perceived comfort. Overhead air distribution diffusers have also been shown to provide good head to toe temperature variations without disrupting the benefits of a stratification zone.

(+) Ventilation Effectiveness: Fresh air supply is introduced to the space low to the ground. As the air warms, the air rises, and pollutants are carried toward the ceiling by the warm air. Rather than mixing the air with the entire space, fresh air is provided to the breathing zone. The efficiency of this method of ventilation may actually result in an efficiency of 100%, but has not yet been documented to do so. The perceived indoor air quality is better and may potentially be used to reduce total ventilation airflow, although this is not generally recommended. ASHRAE Standard 62, Table 6.2, lists the ventilation efficiency of these systems as 100% (the same as cooling from overhead).

(+) Energy Usage: UFAD systems may have some energy savings that are greater than overhead VAV air systems because of lower fan static requirements. Economizer operation may be able to be extended in some locations, but is highly dependent on the local climate.

(+) Reduced Life Cycle Costs: Based on the reduction in costs associated with office churn, UFAD systems may have better total life cycle costs. In addition, the benefit of energy savings may make the system look even better.

(+) Reduced Floor-to-Floor Height: The ability to reduce the floor-to-floor height by 1' per floor may result in additional floor space or reduced shell construction cost. The reduction comes from reduced or eliminated ceiling plenums. **NOTES:** *There is no guarantee that an UFAD system will result in reduced floor-to-floor heights, as ceiling plenums are often required to hide light fixtures, speakers, sprinkler piping, and electric wiring as well as assist with acoustical control of the space.*

(+) Improved Productivity and Health: It is often difficult to prove, but recent studies have suggested that productivity may be improved through good indoor air quality and comfort. Since the costs associated with employees far outweigh all other operating costs, savings can be significant.

(-) Cold Floor: One of the most sensitive points of thermal comfort on the body is the ankle. Control of floor temperature may be a critical issue as the potential for a cold floor (which can act as a radiant panel) exists. Also, the sensitivity to cold drafts as the result of floor diffuser placement is an issue that should be adequately addressed.

(-) Building Codes: Since UFAD technology is relatively new, not all building code officials know how to interpret local and national codes. The result is that some life safety issues, in terms of materials, sprinklers, and smoke detectors, may be issues on certain projects.

(-) Condensation: The thermal mass effects of the plenum floor slabs may have a positive effect on sensible load swings. Care needs to be exercised with control schemes which pre-cool the slab. Outdoor air brought into the system must be kept above the dew point temperature of the floor slab. In humid climates, it may be required that the air handler run during the night when the outside dew point exceeds 62°F, if the perimeter envelope is not adequately sealed.

(-) Humidity Control: The impact of local climate and part load control methodologies must be carefully evaluated. The impact of higher supply air temperatures has the potential to negate some of the system's natural latent heat removal capabilities. Design analysis should consider the impact in terms of part load control and control methodology to be sure room relative humidity is kept below 60%.

Sustainability & Load / Design Considerations

SUSTAINABILITY (LEED™ POINTS)

There is a nationwide trend toward constructing buildings that are more environmentally friendly, as a response to dwindling resources and increasing energy costs. This trend is reflected in designing and constructing buildings to meet green building or sustainable design construction standards. The LEED-NC™ standard, issued by the U. S. Green Building Council, is the best known green building program. The LEED (Leadership in Energy and Environmental Design) standard is based on a voluntary rating system that rates a building design on its environmental impact on the community, site, water, energy efficiency, and indoor quality for the occupants. This standard establishes green building objectives in five categories, with a number of credits which may be accumulated. The rating system, based on the number of points, awards the building a green rating which goes from “Certified” to “Platinum”. There are some prerequisites, but other than that, the points may come from any of the five 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. Some systems are easier to justify points than others. UFAD systems are one of those systems with potential points in several areas.

One point may be gained for exceeding ASHRAE 90.1 energy cost budget (ECB) model by 15%, up to 10 points for a 60% reduction, which 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 some advantages in this area since they incorporate potential energy saving features. Lower fan static requirements, as the result of low plenum pressure distribution, may reduce required fan energy (provided there isn't excessive system leakage). Mechanical cooling requirements, equipment size, and part load efficiencies may be improved due to the extended use of economizer mode. In general, UFAD systems have the potential to show energy savings over the required system of the energy budget model.

The underfloor system may well aid with qualification in two credit areas - Material and Resources. One potential credit area, with up to 3 points, is Building Reuse. If the project involves an existing building, the percentage of building shell reuse would help obtain these credits. The use of a raised floor gives the architect a range of options to achieve these goals. Then, depending on the location, it is possible that the floor system used would qualify for the regional credit, if the site were within a specified distance of manufacture. If concrete floor panels are manufactured from recycled fly ash or similar materials, they too may qualify for a Recycled Material Content credit.

UFAD systems have the potential to qualify for points in two areas in the category of Indoor Environmental Quality. Note, however, that UFAD systems are not rated by ASHRAE as having any advantage in ventilation effectiveness (Standard 62, table 6.2).

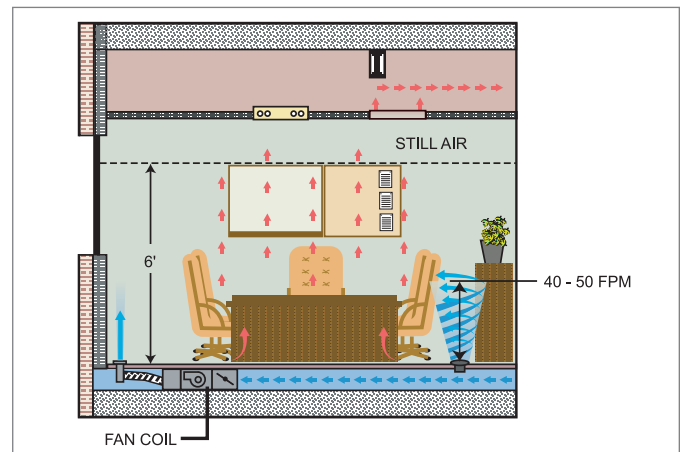
In the category of System Controllability, where the LEED standard requires interior zones to provide control to at least 50% of the occupants. Since an UFAD diffuser provides individual control, the system is nearly automatically qualifies for this point. Another area is the credit related to Thermal Comfort. Since UFAD systems have been shown to provide a high degree of personal comfort, the system may qualify for this credit as well. Of course, properly designed ceiling systems should also qualify.

UFAD systems provide an potential method of achieving points on projects seeking LEED certification. Remember that certification is based on the total building system and that the points and overall rating for a specific project are dependent on the design of the project.

LOAD/DESIGN CONSIDERATIONS

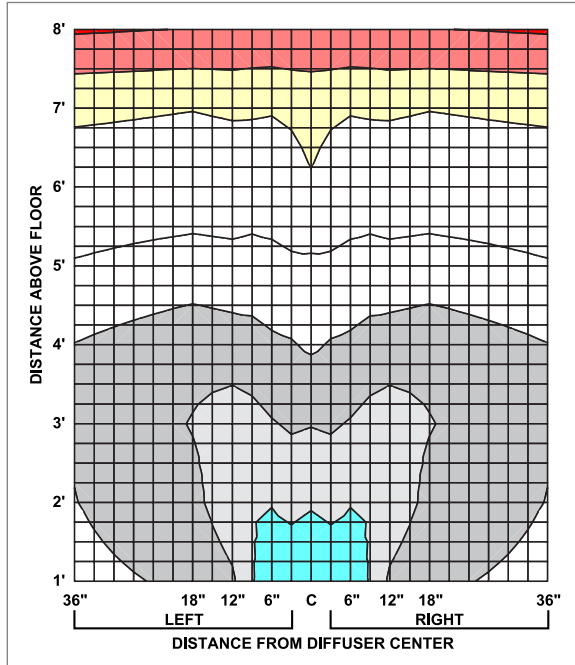
The design for effective UFAD applications assumes that the floor diffusers provide a well mixed zone in the lower portion of the room. Return air, as well as the heat of lighting elements, travels upward through natural convection, and is carried back to the HVAC system. If the throw from the diffuser is too long, it may cause stratified air (and heat) to circulate back into the occupied zone, which would result in poor temperature control and, possibly, inability to manage the load. The FPD-R diffuser throw is a function of both airflow and ΔT . Experience shows that space loads are often overestimated, in part, because occupants are not all present all the time, and that there is some undefined level of radiant cooling. Originally, most UFAD projects were designed around a supplied air quantity of 100 cfm/occupant, at 10°F room to discharge ΔT . When commissioned, however, many of these projects find that this is both too much cooling, and that humidity control is difficult with only 10°F ΔT . As a result, many projects have elected to reduce the underfloor supply temperature from 66°F to 62°F and the supply rate from 1 cfm/ft² to 0.8 cfm/ft² or less.

UNDERFLOOR MIXING ZONES

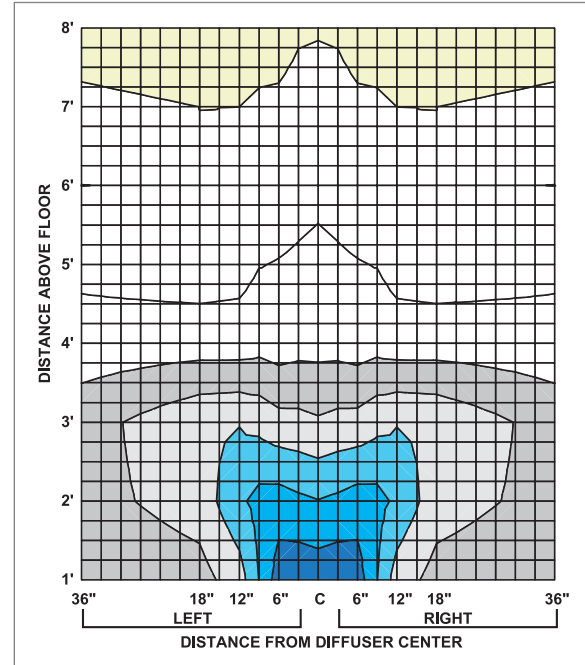


Temperature & Velocity Profiles

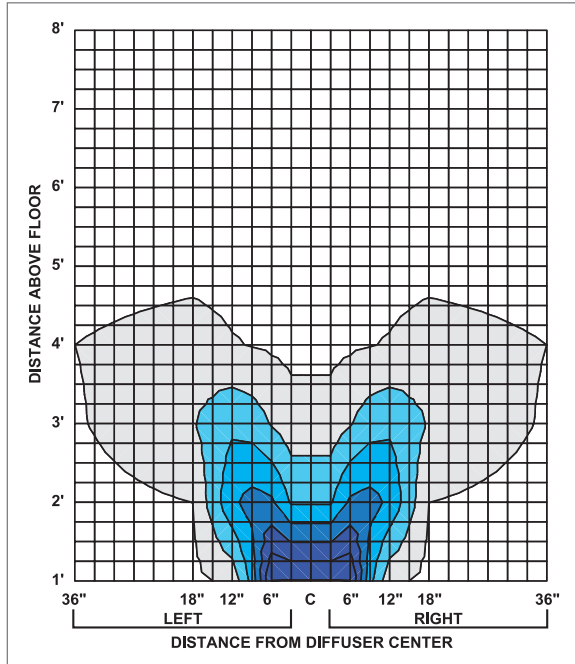
FPD-R, TEMPERATURE PROFILE: 10° ΔT, 100 CFM



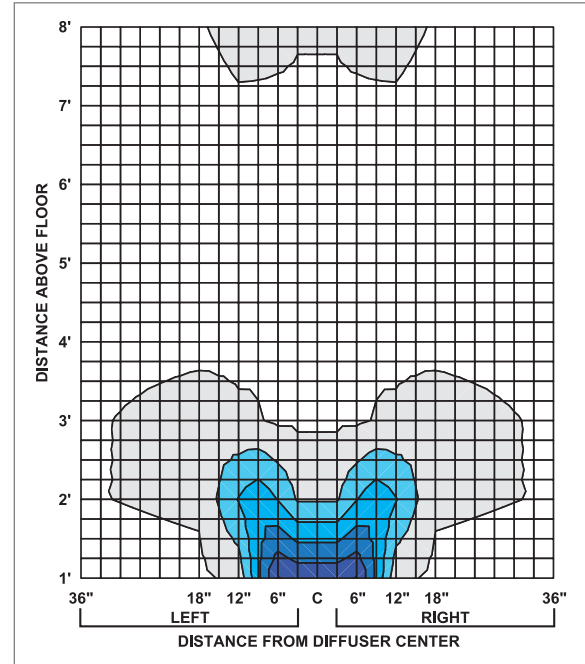
FPD-R, TEMPERATURE PROFILE: 15° ΔT, 80 CFM



FPD-R, VELOCITY PROFILE: 10° ΔT, 100 CFM



FPD-R, VELOCITY PROFILE: 15° ΔT, 80 CFM



UNDERFLOOR PRODUCTS ENGINEERING

ASHRAE Standard 55-2004 recommends a maximum of 5°F vertical stratification in the comfort zone. The diffuser should be selected with this criterion in mind. At the perimeter, or in conference rooms, where higher cooling demand requires considerably more air than in the normal interior zones, there are other considerations. With the typical supply of 65°F air, the quantity may be such that

the diffuser throw may create unwanted mixing in the upper part of the room.

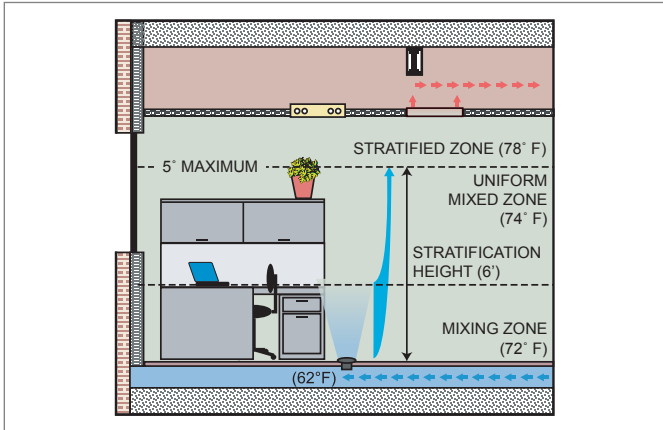
At high loads, with one (1850) underfloor grille located in every third panel, it is obvious that supplying 65°F air has the potential to result in very long throws. A similar analysis can be made for closed conference rooms. Conference rooms are not as critical as open perimeter

zones; nonetheless, high room velocities are likely. One solution is to supply such spaces from overhead. Using the Krueger KUFM mixing VAV Air Column terminal, 55°F air is available for use in both perimeter and interior high-load locations. *NOTES: Locating cooling coils against the slab in an underfloor application is not recommended. The drainage of the condensate pan probably requires condensate pumps, and the failure mode may be very severe.*

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Load / Design Considerations & Duct Work Design

FPD-R, MIXING ZONES



DUCT WORK DESIGN

Benefits of an UFAD system are the ability to reduce duct work associated with air distribution downstream of the zone terminal units and use an airflow plenum underneath a raised floor for low-pressure distribution to the room diffusers. Current research indicates that the maximum distance from the point of injection under the floor to the furthest diffuser not exceed 50 ft; some sources recommend as little as 35 ft maximum distance. If the distance from the edge of the core to the perimeter is less than 50 ft, the KUFM parallel mixing units may be located at the edge of the core structure, thereby eliminating all duct work over the open office areas. A zone should not exceed 4000 ft² in this application. The KUFM unit is sized perfectly for this application.

Air Highways

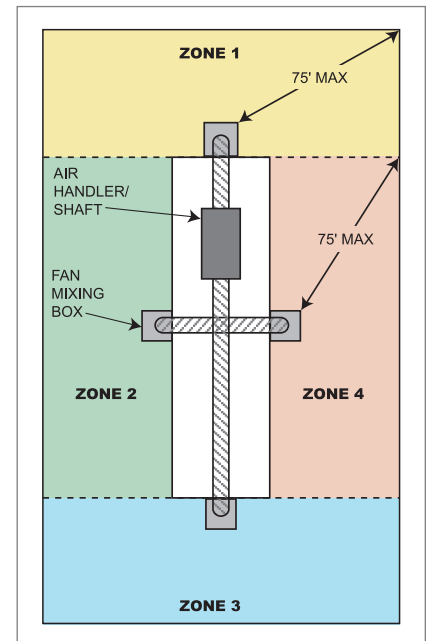
One commonly used plenum distribution technique is to use air highways within the plenum to distribute zone supply air to multiple points within the plenum. These should be sized like normal duct work (limit mains to 1,200 – 1,500 fpm and

dampened branch outlets to 800 – 1,000 fpm). When large air-column type mixing units are employed, typically supplying 10,000 cfm, air must be distributed away from the unit, typically within the plenum. If air highways need to be employed, future rearrangement of furniture/partition zoning above the floor will likely require similar duct work adjustment under the floor, negating some of the cost savings. Also, air highways almost always cause service utility rerouting when laying out power and communications. Further, a maximum discharge velocity, into the plenum, of 1000 fpm has been recommended to avoid unwanted turbulence in the underfloor plenum resulting in non-uniform air distribution to the UFAD units.

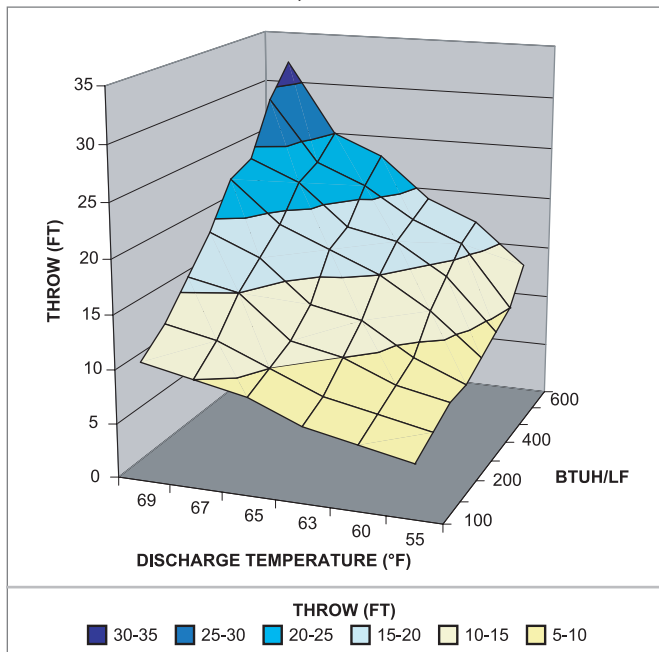
Smoke Partitions and Fire Walls

Whenever plenum areas become too large, they inevitably cross over partitions or walls that need to meet life safety code requirements and extend down through the plenum to the floor slab. During the process of HVAC zoning, attention must be given to these lines so as to not cross over them. If air needs to be transferred over, it may be done so with a hard duct sleeve with the appropriate smoke and/or fire damper installed per code.

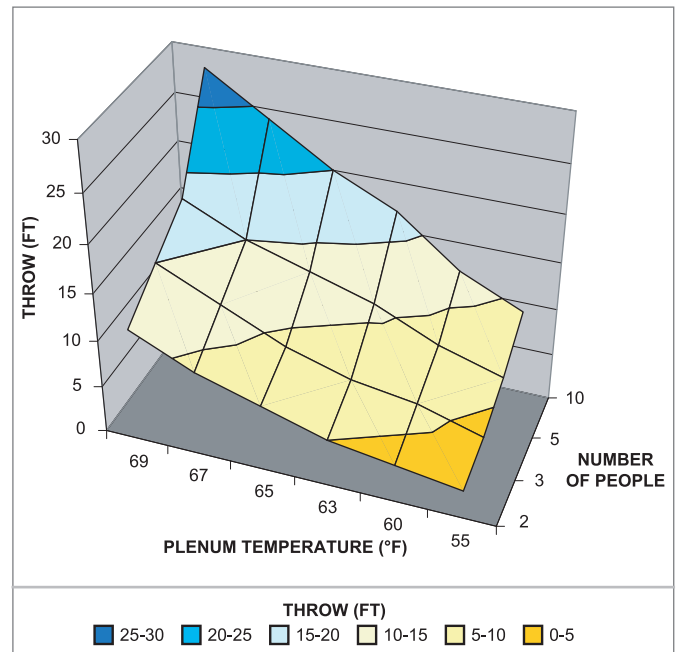
ELIMINATION OF DUCT WORK



THROW VS. ΔT VS. LOAD, DIFFUSERS AT 6' SPACING



CONFERENCE ROOM: NO. OF PEOPLE PER GRILLE

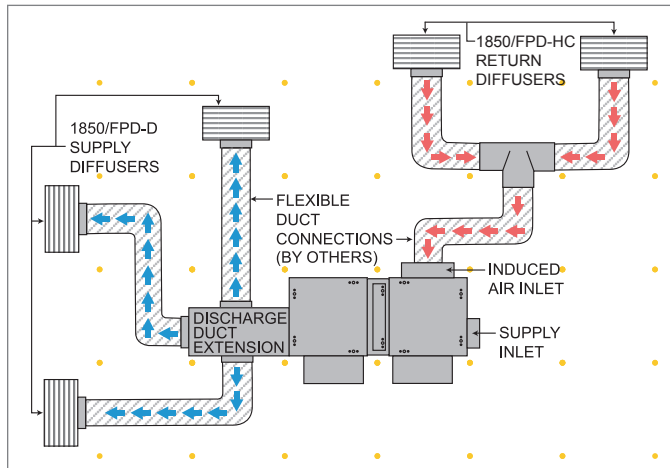


Load / Design Considerations & Duct Work Design

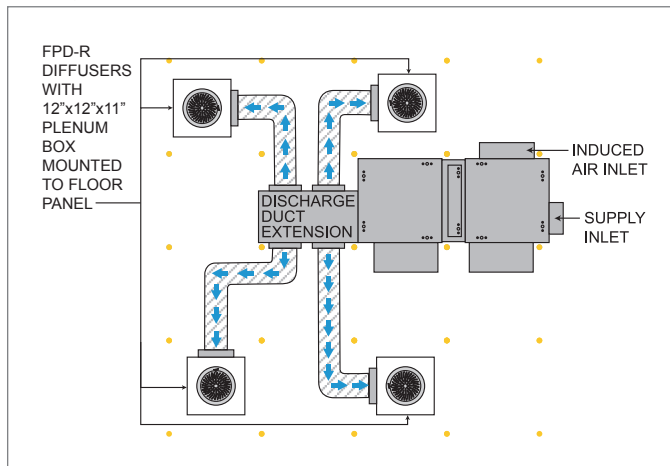
Leakage

The major problem identified in UFAD projects that are not operating as designed has often been traced to excessive leakage. Leakage into the occupied space is not a serious issue. Leakage into column covers, interior wall cavities and perimeter curtain wall cavities is a serious problem. Many UFAD systems rely on warm return air to offset the 55°F coil discharge temperatures required to maintain a maximum 60% RH in the space. Excessive leakage often lowers ceiling return air temperatures, and therefore creates colder supply temperatures if humidity control is to be maintained.

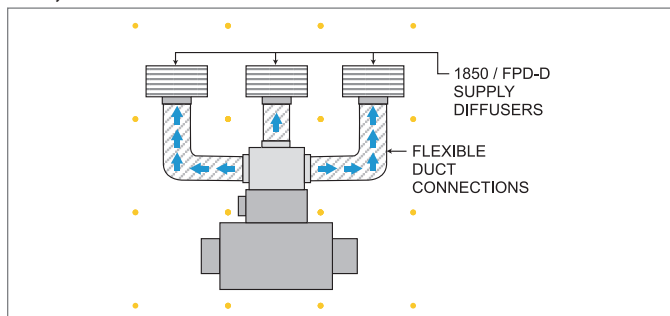
KUFS, DUCTED RETURN



KUFS, LOCALIZED HIGH-COOLING DEMAND



KBF, PERIMETER HEATING



HIGH HEATING AND COOLING DEMAND DESIGNS

How the perimeter and high load interior zones are heated and/or cooled depends primarily on the magnitude of the load and whether or not simultaneous heating and cooling is required. Typically, the need for continuous cooling in many interior zones, combined with the mass effect of the slab, makes it impractical to switch over the central equipment to heating. Often, a number of separate heating devices will be designed for the perimeter zones, creating a hybrid system with UFAD heating that is reserved only for the interior during morning warm-up situations. Following are several methods to accomplish such special zone temperature control needs:

- 1) **Perimeter Series Fan Terminal, Return Ducted:** In full cooling mode, the KUFS Series underfloor terminal takes cold air from underfloor and boosts the supply to the perimeter. Discharge is either ducted to the 1850 grilles with FPD-D boots, or to a separate plenum supplying a number of 1850 grilles. The 1850 grilles with FPD-HC dampers are set to supply cold air to the spaces near the perimeter with cold air from underfloor, and the connection to the KUFS closed. When the cooling demand is less, the KUFS mixes return air, ducted from the space with 1850 grilles attached to FPD-HC boots set as a return, and cool plenum air is induced in the primary air inlet, so as to manage perimeter loads in response to a thermostat. In heating demand mode, Krueger's KUFS series fan unit, utilizing either electric or hot water heating coils, will draw air off the floor through the FPD-HC floor diffusers with the underfloor damper set to minimum ventilation air flow setpoint. Krueger's KUFS employs a conventional series fan control and is available with an ECM motor for extra control and energy savings.
- 2) **Interior Zone High Cooling Areas:** A KUFS series fan terminal with ducted supply air may be used to provide additional interior cooling. A KUFS series fan unit mixes ducted 55°F supply air with plenum air, which may be ducted from the space with 1850 grilles attached FPD-D boots, or may induce cool plenum air to manage cooling demand loads in response to a thermostat. Discharge is either ducted to the 1850 grilles by FPD-D boots or FPD-R helical diffusers by FPD-B boots.
- 3) **Hot Water or Electric Heating Coils:** A Krueger KBF booster fan terminal unit heats the underfloor air, which is ducted to 1800 grilles with FPD-D boots or to a separate plenum that supplies a number of 1850 underfloor grilles. The KBF uses a conventional fan terminal control and is available with an ECM motor for extra control and energy savings.
- 4) **Overhead Heating and Cooling:** Any number of conventional overhead VAV products, in conjunction with a down-blow linear diffuser or ceiling nozzle diffusers, may be utilized to control skin loads. In most cases, a low profile unit will be required, such as Krueger's KLPS or KLPP low profile fan terminal units, with ducted 55°F primary air. The KBF booster fan terminal unit may be installed overhead for supplemental heating as well. In interior zones, standard VAV terminal units may be employed with conventional diffusers to cool conference rooms using conventional overhead designs. This solution is recommended, as it will not disturb the desired stratification in the interior spaces.

UNDERFLOOR PRODUCTS ENGINEERING

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Control Systems & Installation Costs

CONTROL SYSTEMS

Like any other system, UFAD systems rely on proper design and operation of the controls. 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 Constant Air Volume (CAV) passive diffusers, requiring some type of pressurization control on either the zone mixing unit or central equipment.
- Zone control with CAV diffusers requires adjustment of the supply air temperature at the air terminal. This is best accomplished using the Krueger KUFM fan powered air column mixing units that connect to the zone ceiling plenum return air, that mixes with the primary air.
- Resetting supply air temperature higher under light loads allows additional hours of outdoor air economizer cooling, especially in drier climates. The use of a DOAS system makes this type of control independent of humidity control.
- Nighttime pre-cooling, setup correctly, to avoid potential condensation on the plenum surfaces, may offset or delay thermal decay of the zone SAT.
- Thermostat mounting heights are often set lower because of ADA (Americans with Disabilities Act), from 54" to 48" above the raised floor. This is actually a benefit because, if mounted too high, the thermostat would sense the higher temperatures near the stratification layer, requiring the adjustment of the set point upwards to compensate.
- Systems which use Krueger's KUFM terminal unit to control the zone primary airflow for ventilation requirements may take advantage of demand controlled ventilation, DCV, to reduce primary airflow in lower occupancy periods, which may result in additional energy savings.
- One should adhere to control requirements of ASHRAE Standard 90.1, including setback requirements and optimum start requirements.

INSTALLATION COSTS

Many owners and developers have found that underfloor systems with UFAD reduce costs associated with space reconfiguration. With the churn rates now approaching 50% (one move every 6 months), it is not unexpected to find many new office buildings that use raised flooring. Buildings using UFAD systems have certain cost components that make them more expensive than traditional systems, compensating ones that lower the overall price premium that currently exist for this application.

- The underfloor system is the component with the single largest cost increase, which should be cost justified based on the benefits to the entire service delivery system (HVAC, power, voice, and data) and not against the UFAD alone.
- Local building and fire inspectors often require smoke detectors within the plenum and may require sprinkler protection if plenum depth exceeds 18".
- Generally, HVAC costs for central cooling and heating equipment and duct work mains are no different for UFAD systems.
- Diffuser costs are dependent on the type(s) chosen for the majority of air delivered.
- If a relatively open underfloor plenum is used, significant duct work savings may be realized, compared to a typical overhead air distribution system.
- Controls costs should be similar to traditional systems when basic zoning is unchanged.
- Testing and balancing savings may be realized from CAV pressurized plenum designs, which are essentially self-balancing.
- Leakage control may be a very expensive cost. All the trades involved in construction must be aware of the requirement for sealing potential leaks, and it has been recommended that frequent inspections be conducted to assure that leakage and sealing issues are understood and followed.

Energy Usage & Design Considerations

OPERATION & INSTALLATION CONSIDERATIONS

Office building UFAD systems are quite new, making it difficult to obtain actual operation and maintenance cost data to compare against traditional HVAC systems. Operation and maintenance costs are primarily replacement costs for equipment and labor expenses associated with maintaining the HVAC system and responding to occupant complaints. While many engineers believe that UFAD system may prove to be more costly to service, research suggests that the frequency of occupant complaints will be reduced when they are given some individual control of their local environment.

ENERGY USAGE

UFAD systems have the potential to save energy in comparison to traditional designs. The bulk of these savings come from reduced fan energy that is associated with lower static pressures. Energy costs remain difficult to predict because, to date, there is no energy simulation software that accurately models UFAD system performance. Excessive leakage may override energy savings from reduced fan pressure requirements.

DESIGN CONSIDERATIONS & RECOMMENDATIONS

- 1) Do not eliminate the suspended ceiling. With the quieter operation of a UFAD, acoustical treatment of the space will be required.
- 2) Keep plenum depths below 18" to avoid a potential requirement for sprinklers. Provide pressure trap floor drains if ceiling sprinklers are installed. **NOTE:** *Verify with local building codes.*
- 3) Do not use too many zoning barriers in the plenum or you will restrict the ease of future rezoning and running of service utilities to various points of use.
- 4) Use multiple vertical drops to avoid air highways, while also meeting the 35 ft to 50 ft guideline for maximum travel to the farthest diffuser.
- 5) Do not include excess safety factors; airflows need to closely match load requirements within the occupied zone so as to not over-air the system. Tests have shown an ideal airflow of 0.6 cfm/ft² for good mixing, while maintaining the stratification height at 6 ft, and keeping the room temperature gradient below 5°F.
- 6) Carefully run loads for both occupied and unoccupied to determine if load credits can be taken; equipment size reduction will benefit the job costs.
- 7) Select diffusers so that T₅₀ throws are never greater than 4 ft to 5 ft, so as to not disturb the stratifications layer. Use CAV passive curved slot helical air pattern diffusers in the interior and uniformly loaded large perimeter spaces.
- 8) Hybrid designs, using conventional VAV air handlers and DOAS systems in high load/variable-load situations maximizes the benefits of the lower AHU supply air temperatures and keeps summer-time humidity concerns under control.
- 9) Placing returns over heat-producing equipment and/or at the outside wall when high solar loads exist will maximize the benefit of the partial displacement ventilation effect.
- 10) DDC controls should be considered basis of design for realizing true UFAD benefits.