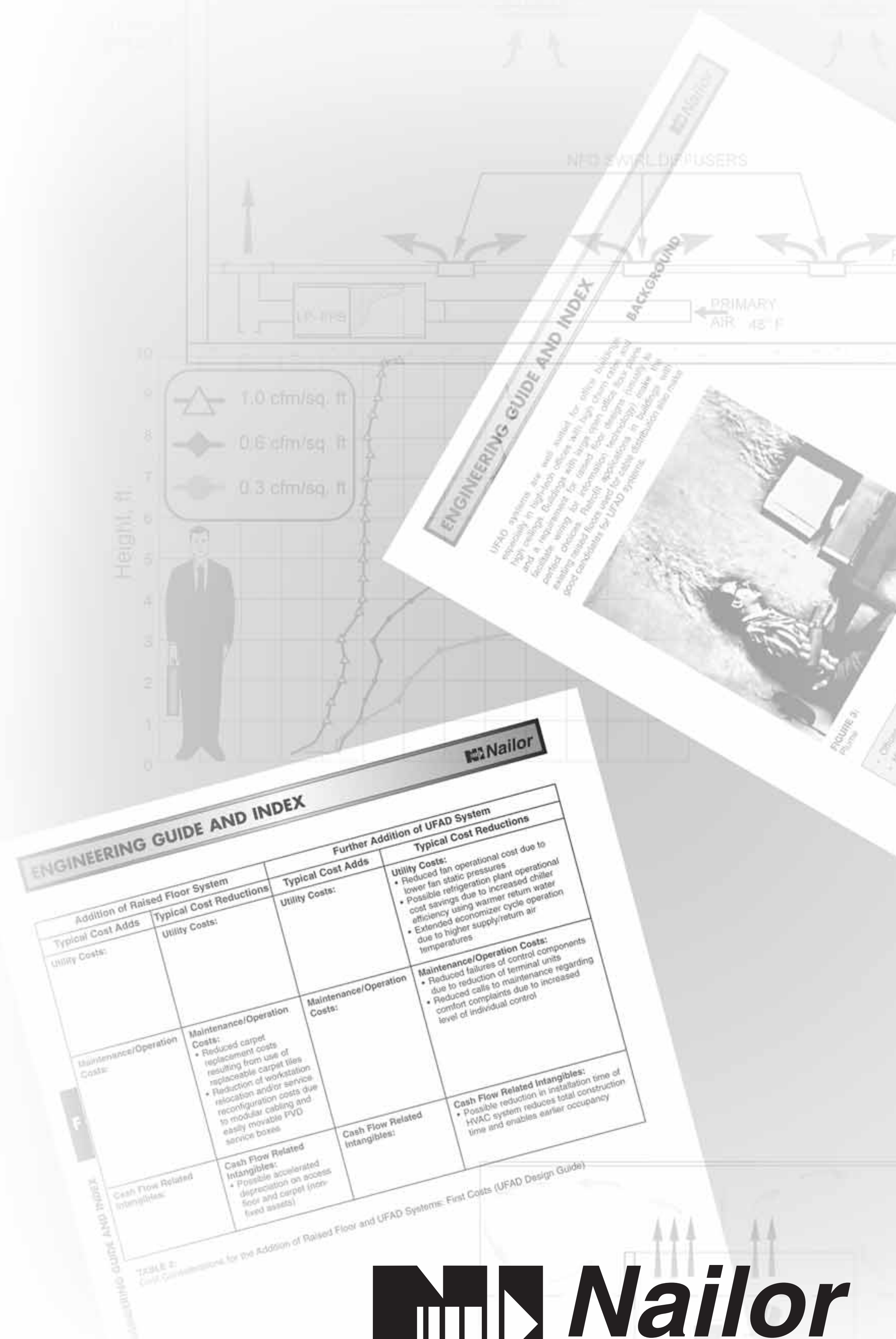


Nailor Industries Inc.

ENGINEERING GUIDE AND INDEX

Contents

Introduction

The number one occupant complaint in modern commercial buildings is thermal comfort. This results in loss of productivity and increased absenteeism by the occupants as well as generally reduced energy efficiency as fans and space heaters clutter the office environment. Employee salaries typically account for over 90% of the operating cost of a modern commercial building, therefore anything that will enhance employee productivity and reduce absenteeism such as increased comfort levels and better air quality can create immense financial benefits. The same is true for retail spaces where increased sales are associated with increased comfort conditions.

As engineers, the design goal is to achieve superior comfort levels for the occupants without sacrificing energy efficiency and dramatically increasing the first cost of the project. One of the main problems associated with achieving this goal is that people in a modern office building tend to be a rather diverse group with different perceptions and requirements. The typical air distribution systems do not accommodate this flexibility well as large portions of modern buildings are now being devoted to open plan offices. The customary highly mixed overhead air distribution systems will provide a uniform environment in the space. This does not however maximize occupant comfort levels, as some people will feel warm as others feel cool at the same conditions. They will also dress differently, especially at different times of the year, and may have different levels of activity throughout the day or depending on their occupations. This diversity in occupant requirements poses an incredible challenge for the air distribution design, which must be very flexible to accommodate the varying situations and preferences. One of the best ways to achieve this flexibility is an underfloor air distribution system with individually adjustable diffusers or with thermostatically controlled diffusers. This allows individuals to set their own preferences and maximize their comfort conditions. (An interesting study showed that people were much more satisfied in an environment that they had some control over, even if they never actually made an adjustment. Just having the ability to adjust the temperature or air velocity will increase occupant comfort levels.)

Underfloor air distribution systems are a relatively new concept in North America. Developed as an improvement over displacement ventilation systems, the moderate amount of mixing in the occupied zone improves comfort conditions while still allowing energy efficient stratification in the unoccupied zones. Used for many years in Europe and Japan they are now gaining popularity as an energy efficient 'green' design method and a personal comfort solution. The use of raised floor systems for the routing of electrical, telephone and computer cabling has provided the financial conditions necessary for widespread implementation of this technology.

The energy savings from the air distribution system alone, even with the elimination of much of the ductwork, generally will not offset the first costs associated with raised floor systems. However when combined with the life cycle savings associated with high churn rates (office layout changes) and the electrical, telephone and computer wiring changes necessary, not to mention improved occupant comfort they are rapidly becoming the systems of choice in modern office buildings.

Green Buildings

An evolving industry trend is toward environmentally friendly, energy efficient, "green" buildings. A variety of new and revised guidelines and incentive programs are being developed to encourage this development, some are even becoming standards for certain regions, federal agencies, state, provincial and municipal governments. These include the use of rating systems such as LEED, Green Leaf Eco-Rating Program, BREEAM Green Leaf and GBC/GBTool.

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System is currently the most widely accepted in North America and is the result of efforts by the U.S. Green Building Council (USGBC) to provide a national standard for what constitutes a green building. This effort has been expanded into many other countries including Canada with the founding of the Canada Green Building Council (CaGBC) and the World Green Building Council.

The LEED rating system assigns a point value to various credit categories. These points are then combined to determine the overall building rating (Certified, Silver, Gold or Platinum). These categories include sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality and innovation and design process. Information on the program is available from the USGBC website at www.usgbc.org.

Sections of particular interest to HVAC engineers include:

- Commissioning requirements
- Additional commissioning requirements
- Minimum energy performance (must meet ANSI/ ASHRAE/IESNA Standard 90.1 or local energy code whichever is more stringent)
- Optimize energy performance (points awarded for energy reductions over minimum requirements using the Energy Cost Budget Method of Standard 90.1) (ASHRAE is also currently developing Advanced Energy Efficiency Guidelines for 30%, 50% and 75% reductions)
- CFC reduction in HVAC&R equipment (zero use of CFC-based refrigerants)
- Ozone protection (use of HVAC&R equipment that does not contain HCFCs)

- Measurement and verification (install continuous metering for equipment such as constant and variable motor loads, variable frequency drives, chiller efficiency, cooling load, air and water economizer and heat recovery cycles, air distribution static pressures and ventilation air volumes, boiler efficiencies…)
- Regional materials (use 20% of building materials and products that are manufactured regionally within a radius of 500 miles)
- Regional materials (of the regional materials above use a minimum of 50% that are extracted, harvested or recovered within 500 miles)
- Environmental quality (IAQ) (meet minimum requirements of ASHRAE Standard 62 using the ventilation rate procedure)
- Environmental tobacco smoke control
- Carbon dioxide monitoring (integrated with BAS)
- Ventilation Effectiveness (design ventilations system to result in air change effectiveness values greater or equal to 0.9 as determined by ASHRAE 129-1997)
- Construction IAQ management plan - during construction (follow SMACNA IAQ guideline, MERV 8 filters on return grilles etc…)
- Construction IAQ management plan - before occupancy (flush building for 2 weeks with 100% outdoor air and MERV 13 filtration or conduct testing procedure consistent with EPA protocol)
- Indoor chemical and pollutant source control (negative pressure and exhaust requirements for housekeeping areas and copy/printing rooms)
- Controllability of systems (provide controls for each individual for airflow, temperature and lighting for at least 50% of the occupants in non-perimeter, regularly occupied areas)
- Thermal comfort (comply with ASHRAE Standard 55 for thermal comfort and humidity conditions)
- Thermal comfort permanent monitoring system (temperature and humidity monitoring to ensure compliance with ASHRAE Standard 55)
- LEED accredited professional (at least one principal participant of the project team to successfully complete the LEED Accredited Professional exam)

Advantages of Underfloor Air Distribution Systems

Enhanced Ventilation Effectiveness

Underfloor air distribution can enhance ventilation effectiveness. Air movement from floor to ceiling efficiently removes heat and contaminants. Since very high air change effectiveness values can be achieved this contributes to LEED Rating.

Improved Indoor Air Quality

Air quality for the occupants is improved as airborne pollutants tend to rise out of the occupied zone with the thermal plumes from people and equipment. Since the air makes a single pass by the occupant and is not mixed back into the lower homogenous zone, occupants enjoy more healthy environments. With floor 'swirl' diffusers, ventilation air is delivered and mixed in the breathing zone, which reduces the concentration of contaminants.

Energy Efficiency

Well designed systems can be more energy efficient than conventional overhead systems. Operational static pressures are generally much lower, reducing fan energy use. This also contributes to the LEED Rating. Thermal plumes created by people and equipment are returned directly to the air handler; therefore, actual room load may be reduced resulting in less actual airflow required into the room which reduces the number of diffusers and fan sizes saving costs and energy. Some of these convective loads from lights, windows, computers and people are returned directly to the central system and are not fully included in the room air side load.

Enhanced Comfort Levels

Higher supply air temperatures enhance occupant comfort levels reducing drafts and improving thermal comfort.

Thermal Storage

Thermal storage in the structure and concrete slab may be used to save energy and reduce peak cooling loads.

Reduced Energy Use

Higher supply air temperatures will increase the economizer hours for dry climates. This increases the system COP.

Individual Control

Individual control of air outlets enhances occupant comfort levels and increases employee productivity. Both manual and automatic systems are available. These options contribute to LEED Rating.

VAV Control

Automatic controls for air outlets are available to provide variable air volume temperature control and monitoring to ensure thermal comfort of occupants. This also tends to supply ventilation air to the specific area it is required enhancing air movement and air quality in the occupied areas. This contributes to LEED Rating.

Reduced Life Cycle Costs

Use of raised access floor systems can significantly reduce life cycle costs for buildings with high churn rates. Diffuser locations can be easily changed to accommodate revised floor layouts without involving interior contractors.

Reduced Building Costs
Building costs may be reduced due to lower floor to floor heights and reduced or eliminated ceiling plenums.

Recycled Materials
Products such as the Nailor ANFD floor swirl diffuser utilize 100% recycled aluminum, which helps to protect our environment and contributes to LEED Rating.

Disadvantages of Underfloor Air Distribution Systems

Unfamiliarity
Building occupants often don't know they can easily adjust the floor diffusers to improve their thermal comfort

Lack of Design Guidelines
It is possible that at very low airflow conditions and low supply air temperatures the stratification levels in the room will lead to uncomfortable temperature variations. Constant volume variable temperature systems will eliminate this rather unlikely condition, as will fixed minimum airflows on variable volume systems.

Not All Diffusers are the Same
At high airflow conditions, some diffusers will cause the room to approach a well-mixed system eliminating some of the energy benefits associated with thermal stratification.

Architectural Layouts
Diffusers must be located and/or relocated so as not to interfere with occupant positions and furniture placement. Clear zones must be established around individual diffusers as locally high velocities and low temperatures will create regions unsuitable for long-term occupancy.

New Technology
UFAD, while rapidly gaining acceptance, is still widely considered to be an unknown and unproven technology, despite the thousands of installations. This lack of understanding, experience and acceptance can result in possible problems with construction trades, project managers, code officials and building operators.

Floor Leakage and Spills
Transitioning access floor installations into areas such as washrooms, kitchens and lunchrooms can pose challenges requiring the use of waterproof membranes on top of the floor and difficulty in diffuser placement. (Plumbing costs may be reduced to help offset this).

Applications
There are three primary methods of room air distribution, conventional overhead mixing systems, displacement ventilation and underfloor systems. The conventional overhead mixing systems have been widely applied in North American buildings and are familiar to most people. Briefly, they consist of ceiling supply diffusers and ceiling return diffusers. Supply air is introduced into the room through these ceiling mounted diffusers at a relatively high velocity where it is directed across the ceiling. Due to the velocity of the air, it rapidly entrains room air causing the supply jet to rapidly approach room temperature and to slow to a lower more comfortable velocity before entering the occupied zone. This system works very well in most interior zone applications for both heating and cooling conditions and provides a well-mixed comfortable environment throughout the space without excessive drafts or local temperature variations. This is also the major drawback as the well-mixed space temperatures and velocities will only satisfy the majority of the occupants and will typically not allow for individual adjustments and comfort preferences.

Displacement ventilation systems, (see Figure 1), supply low velocity conditioned air through large low velocity diffusers located generally at a low sidewall location. As this air is supplied directly into the occupied zone, it must be at very low velocities and at temperatures approaching room temperature to maintain a comfortable environment. These systems have many drawbacks that tend to eliminate their selection in a modern office environment; however, in areas with high ceilings and high heat loads (i.e. manufacturing facilities) they can be ideal. In an office environment, the increased supply air temperatures will require large volumes of air (increased fan energy and humidity control problems), necessitating large diffuser and wall areas. As this large volume of air flows into the room it settles across the floor until it is entrained by thermal plumes (see Figure 2 & 3), from heat sources in the room. These plumes will create a stratification layer in the room with a height dependent on supply air quantity, temperature, the height and magnitude of the heat sources and overall room load. This stratification height is difficult to control in all circumstances and could lead to uncomfortable conditions due to excessive temperature differences and result in poor comfort conditions in the occupied zone. Heating conditions can also be very challenging, especially in areas with high ceilings, as the stratification levels will cause zones with stagnant airflow and also lead to short circuiting of supply air. It also has the same drawback as overhead systems as it does not allow for individual adjustments and it is even more difficult to create individual zones.

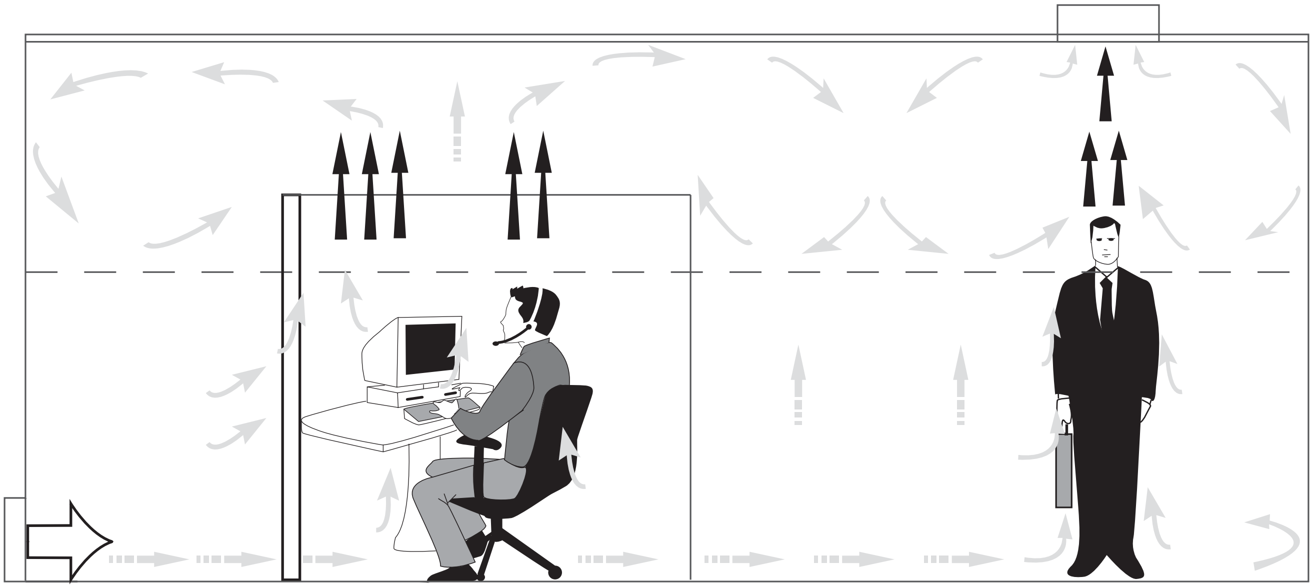


Figure 1:
Displacement Ventilation Room

Figure 2:
Hybrid System

UFAD systems, (see Figure 2), are basically a hybrid of these two concepts. Supply air is introduced directly into the occupied zone through specially designed floor diffusers. These floor diffusers are engineered to rapidly mix supply and room air in the occupied zone and create a generally well-mixed environment maximizing comfort conditions while allowing a larger cooling load to be handled than typical displacement ventilation systems. Above the occupied zone, the thermal plumes (see Figure 3), from people and equipment create a stratification layer. The rapid mixing by the supply diffusers allows a supply air temperature to be used that is generally cooler than displacement ventilation however not quite as cool as overhead systems. The diffusers themselves are all individually adjustable either manually or automatically and allow individual control of the local environment for the occupants. This enhanced comfort level is one of the primary benefits of this concept.

UFAD systems are well suited for office buildings, especially in high-tech offices with high churn rates and high ceilings. Buildings with large open office floor plans and a requirement for raised floor designs (usually to facilitate wiring for information technology) make the perfect choices. Retrofit applications in buildings with existing raised floors used for cable distribution also make good candidates for UFAD systems.

Figure 3:
Thermal Plume

- Offices with large open office floor plans
- High-tech offices
- Dot-com offices
- Call centers
- Trading floors
- Schools
- Television studios
- Light manufacturing installations that don't involve spillage of liquids, etc.

Retrofit

UFAD design has its highest advantages in new construction. The option of installation of raised floors is restricted in a large majority of buildings due to limited floor to floor heights. Current designs use 12" to 18" (.3 to .46 m) high floors, and difficulties fitting the raised floors into the existing floor spacing and satisfying occupant requirements range from moderate to impossible.

Information Shortages

Design Issues

As with any new technology, there are design issues that are either lacking design guidelines or completely unknown. Among these issues are the amounts of heat transferred from the slab and the floor panels to the supply air as it travels under the raised floor. If the slab is warmer on the underside where exposed to heat in the return air plenum of the floor below, then some heat will be transferred to the supply air. Supply air temperature will increase with distance from the plenum inlet. A similar condition exists at the floor panels. The warmer room will transfer some heat to the supply air in the plenum and it will increase similarly with distance from the inlet.

There are questions raised as to whether the slab can be economically pre-cooled at night and used for thermal storage during the occupied hours. There are few studies attesting to the benefit of this control strategy.

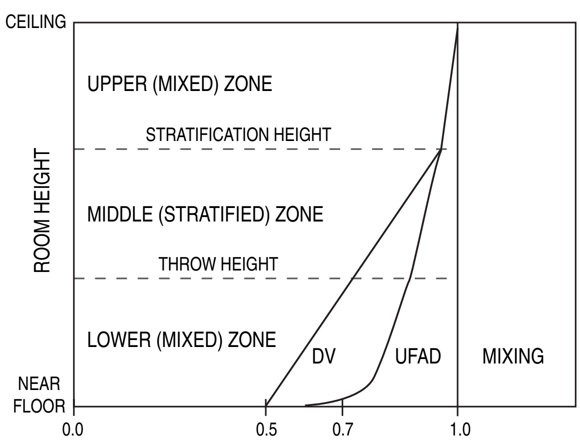
Questions surrounding the impact of UFAD diffusers on room stratification, ventilation effectiveness, ventilation efficiencies, behavior of thermal plumes at solar heated windows, interaction between thermal plumes and varying airflows, and health and comfort benefits still have to be answered by ASHRAE and other research groups.

UFAD systems are ideal for areas with high ceilings as they provide air directly into the occupied zones.

Design Considerations

Room Air Stratification Design

An understanding of controlled and optimized thermal stratification is critical to the increasing use of these systems; however, there is a critical lack of sound test data from which a guideline and design tools for calculating the energy needs and air distribution requirements on UFAD systems. We need answers to questions such as, "What portion of the convective heat sources are contained in thermal plumes and can be neglected as space load or room cooling air quantity? What are the effects of supply air flow, supply air temperature, ceiling height, and cooling air quantity on room stratification?



Temperature [$(T - T_S) / [T_E - T_S)$]

Figure 4:

Comparison of typical vertical temperature profiles for underfloor air distribution, displacement ventilation, and mixing systems.

Temperature Gradient

The room comfort levels are very dependent on the type of diffuser used. The general plan is to establish a thermocline in the room at a stratified height that includes the head height of the average occupant.(see Figure 4) In the case where the average occupant is seated, the stratification height would be about 4.5' (1.4 m) above the floor. In the case where the average occupant is standing, the height would be about 6' (1.8 m) above the floor. The lower zone will always exist, and the height is set by the vertical air projection of the floor diffusers and the ratio of the space heat load to the supply airflow to the space. The air below the thermocline should be a fairly homogenous mixture with near constant temperature. This is achieved by the high mixing performance and high induction rate of the swirl diffusers.

The air above the thermocline is stratified and acts similar to the air in a pure displacement type system. This zone does not always exist. If the vertical air projection from the diffusers is too high, this zone is completely eliminated and the entire room becomes a dilution system where all the air is mixed like in an overhead system. When the second zone does exist, thermal plumes are active in this area carrying heat, contaminants and humidity to the boundary layer near the ceiling where air is returned to the air handler. Temperature is not constant. Outside the plumes, it is rises gradually as shown in Figure 5.

Above the stratification layer is an upper mixed zone or boundary layer very near the ceiling. In this boundary layer, the air is nearly constant in temperature and composed of warm, contaminated air. If jets from the diffusers penetrate into this zone, it may cease to exist. When this zone is disturbed by the diffuser jets, heat and pollutants are returned to the occupied space.

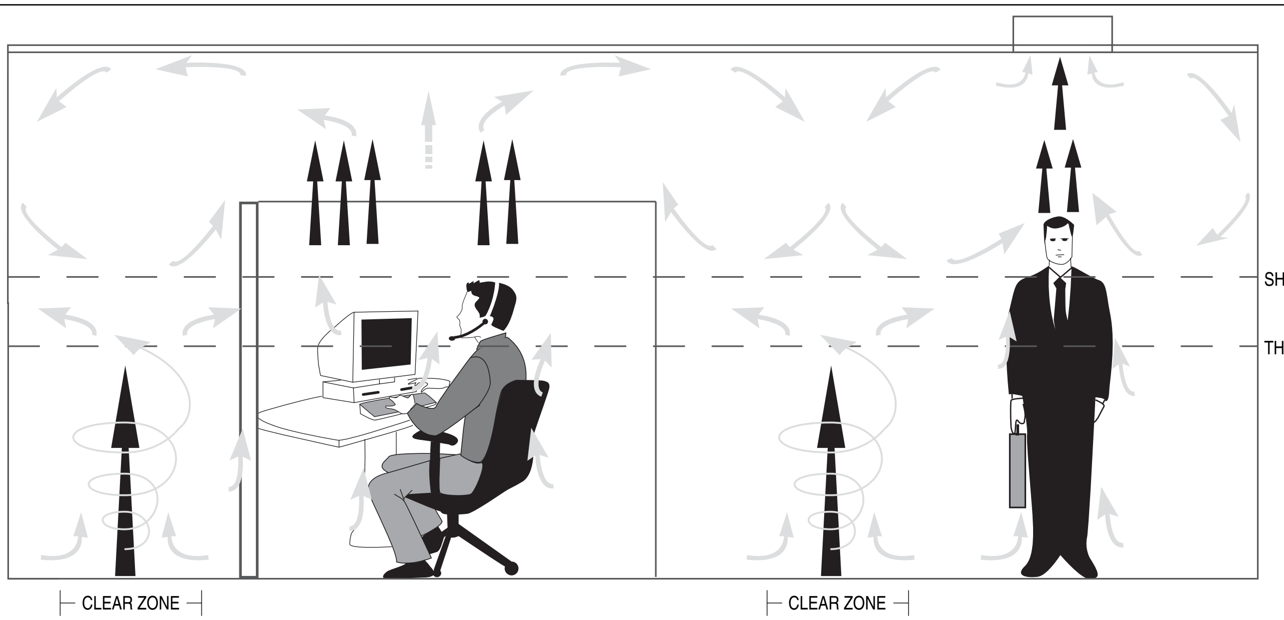


Figure 5:

Underfloor air distribution system with diffuser throw below the stratification height.

Supply Air Temperatures

Minimum supply air temperatures should be maintained in the range of 61 to 65° F (16 to 18° C). Temperatures cooler than this can chill people's feet, even through the soles on their shoes. These low temperatures can also cause chills to an occupant located near a diffuser. Supply air temperature reset control methods is preferable to constant SAT control strategies; however, be prepared for slow changes in room conditions as SAT changes due to the mass of the slab that acts as a heat sink. One method of controlling SAT is to control off of the return air temperature in the return air plenum. This will maintain the thermocline at the desired location, thus maintaining optimum space comfort and minimum energy expended, regardless of the space loading.

Load Calculations

In properly designed systems, convective heat loads above the stratification levels in the occupied zone will not enter the occupied zone, but rather rise through the second zone to the third and return to the air handler. As such, these loads are not room loads.

Code and Standard Issues

UFAD systems are still a new technology in our industry. As such, it is not well covered by local codes or recognized standards and authorities. ASHRAE Standards 55, 62.1 and 113 all have direct relevance to UFAD systems, yet none of them directly addresses UFAD, and Standard 113 does not address UFAD at all. Future revisions to those standards will correct some or all of the deficiencies; however, in the mean time, coordination with local fire and building codes and local code authorities should be sought early in the design process. Arguments can be made that fundamentally, the floor plenum should follow the same codes that cover ceiling plenums.

Condensation and Dehumidification

Humid climates will need more dehumidification than drier climates; consequently, there will not be as many economizer days in the humid climates. Days when the outdoor air temperatures are above 55°F. (12.8°C.) will usually require some design to provide dehumidification to the space, whereas in drier climates, days when temperatures are below 65°F. (18.3°C.) outdoor air may be acceptable as cooling air without further dehumidification. Depending on the local climate more economizer days may be available to improve energy efficiency as well as increased chiller COP, which contributes to LEED rating.

Configuration

One difference between overhead and underfloor systems is that the UFAD systems are usually configured to have a larger number of smaller capacity outlets. Floor diffusers are usually in close proximity to the occupants. The close proximity to the occupant optimizes the occupant's ability to adjust the airflow from the diffuser to fit his personal requirements. Floor manufacturers normally supply floor tiles with precut holes for diffusers, power/voice/data terminals and any other outlet boxes; therefore, it is imperative to decide on the diffuser and other outlet selections prior to ordering the floor tiles.

Interior Zones

Interior zones are typically cooling only zones and do not require heat. Normally they are served with about 0.6 cfm/ft^2 (3 L/s/m^2) per diffuser. Occupant satisfaction is maximized if the open office diffusers are designed to be manually adjusted to fit the desires of the local occupant. However, conference rooms, training rooms and any other areas that are enclosed and subject to varying heat loads should be served with VAV diffusers. VAV diffusers should have modulating actuators rather than 3 point floating devices to keep all the actuators in one zone synchronized. Actuators with 3 point floating control will become lost during the day and have to be recalibrated or zeroed regularly.

Perimeter Zones

Perimeter zones have both heating and cooling loads. The loads are also much more variable than the interior loads as heat gains or losses at the curtain wall dictate the system requirements. VAV strategy of some sort is preferred for the perimeter zones. Usually, the perimeter zones and interior zones are separated under the floor. In this configuration, different SAT strategies can be utilized. Variable temperature and variable volume supply air works best in this application. Care must be taken to insure that the perimeter diffusers do not have long throws. The diffusers should be designed with throws that have no more vertical projection than the interior diffusers, about 4.5' (1.4 m) to about 6' (1.8 m) above the floor on a neutral wall. This will keep the perimeter diffusers from affecting the thermocline in the occupied space and mixing heat and pollutants back into the room.

Acoustic Performance

Radiated sound from equipment such as fan coils or fan powered VAV terminal units that may be located below the floor will be less than if similar equipment were mounted overhead with a conventional ceiling. Radiated sound can easily penetrate a lay-in ceiling, but penetrating steel and concrete panels is tough. Radiated attenuation is probably twice that expected from a single layer of gypsum board as laid out in ARI 885. Discharge sound can be a problem. In overhead systems, duct runs are usually fairly long providing a large amount of attenuation. In underfloor applications, the reverse is true, short runs and little attenuation. Units that are inserted directly into the septum separating the interior and perimeter zones will have almost no attenuation between the unit and the discharge grilles at the perimeter. When fan powered VAV terminals or fan coils are applied, they should have silencers or at least internally lined duct runs downstream for attenuation. It has become popular to use units with 1000 cfm or more at the terminal unit. Airflows from these types of equipment in this range are noisy if not attenuated.

Control Strategies

Controlling the height of the thermocline in the space is of utmost importance for comfort and energy consumption. General guidelines would suggest that a reasonable target is about 0.6 cfm/ft^2 (3 L/s/m^2). See Figures 6 and 7. As you can see from Figure 7, resetting supply air temperature in combination with adjusting room airflows is advisable to achieve optimal room conditions throughout the occupied zone. Note that the space thermostats may not be set the same as with overhead systems. The temperature should be set to maintain the thermocline and occupant comfort. The temperature gradient in the occupied space should be no more that 5°F. (2.8°C) (from ankle to neck) to maximize comfort, while the temperature gradient from the supply air to the return air should be 20°F. (11°C) to minimize energy use. Comfort can be achieved while destroying the stratification layer if the room is oversupplied with air. Sensor height is important. If the sensor is near or above the thermocline, it should read higher than the occupied zone temperature. See Figure 8 for a description of different temperature profiles based on different airflows. The graphs in Figure 8 are not measured data, but rather illustrations shown for demonstration purposes only.

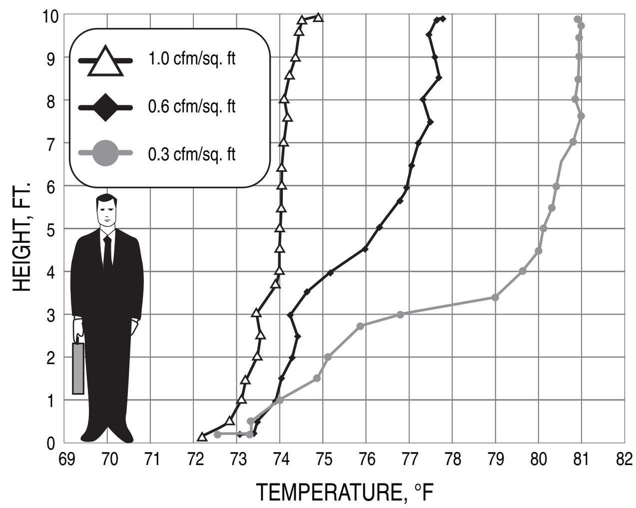


Figure 6:
Effect of room airflow variation at constant heat input, swirl diffusers, interior zone.

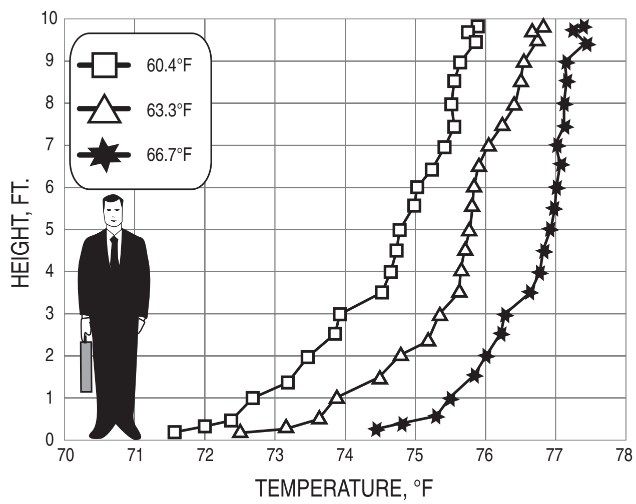


Figure 7:
Effect of supply air temperature variation at constant heat input, interior zone.

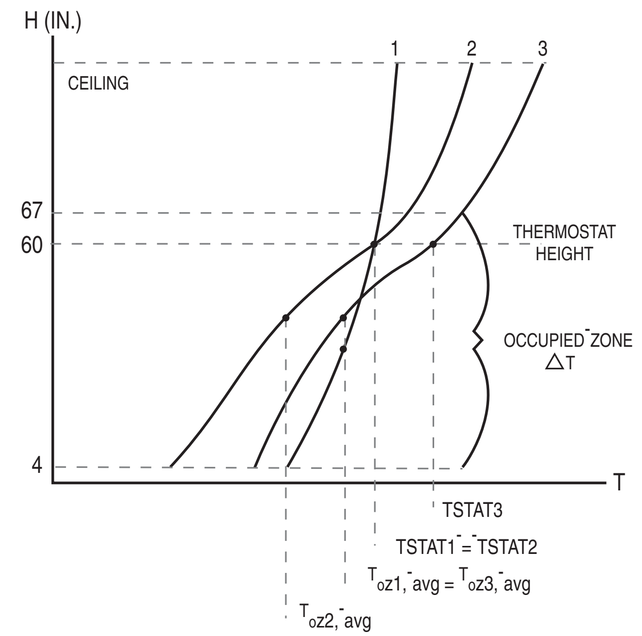


Figure 8:
Example sequence for controlling thermal stratification.

Underfloor Plenum Design

Thermal Decay

Airflow under the floor is different from airflow through overhead ducts that are insulated. The air in the floor plenum is in contact with the underside of the raised floor and the top of the concrete slab below. If the slab is warmer on the underside where exposed to heat in the return air plenum of the floor below, then some heat will be transferred to the supply air. Supply air temperature will increase with distance from the plenum inlet. A similar condition exists at the floor panels. The warmer room will transfer some heat to the supply air in the plenum and it will increase similarly with distance from the inlet. While additional research is needed to provide acceptable guidelines, some current designers suggest calculating a 0.05 to 0.15° F. (0.1 to 0.3° C) temperature rise per linear foot traveled by the air from the inlet to the outlet. This results in a maximum throw distance under the floor of 50 to 60 ft. (15 to 18 m) for typical applications. Horizontal ducts and air highways may be used to bridge distances between inlets and outlets; however, velocities in the ducts should be limited to 1200 to 1500 fpm (6 to 7.5 m/s). Outlets can be located all along the length of the duct, but outlet velocities should be limited to 800 to 1000 fpm (4 to 5 m/s). Balancing dampers should be considered for optimum control of airflow.

Obstructions Within the Plenum

Care should be taken to plan, coordinate and control the placement of cable trays and ducts below the floor. Stacking anything to close proximity to the floor tiles will obstruct airflow through the plenum.

Air Leakage

Plenum pressures in UFAD systems should run between 0.3 and 0.8 in. w.g. (0.07 to 0.2 pa) for normal operation. Even at these low pressures, leakage is an issue that must be considered. Leakage occurs between the floor panels and around walls if the panels are not sealed well. Leakage rates of 10 to 30% due to construction issues are normal. Leakage rates between the floor panels with different carpet tile configurations are shown in Table 1. As you can see, the method or pattern used for laying carpet on the floor tiles has a significant effect on the leakage. Use caution in oversizing the air supply to the room; air loss from between the tiles plus the heat loss through the floor can supply a large part of the cooling requirement at low load conditions. This could move the thermocline upwards using more energy and causing the room to be uncomfortable.

Plenum Pressure (in. H_2O [Pa]*)	Carpet Tile Configuration		
	None	Aligned	Offset
0.05 [12.5]*	.68 [3.5]	.29 [1.5]	.14 [0.7]
0.1 [25]**	.96 [4.9]	.41 [2.1]	.20 [1.0]

Table 1:
Air Leakage Through Gaps Between Floor Panels (cfm/ft^2) [L/(s m^2)]

Structural Strength of the Raised Floor

There is no current standard for testing structural integrity of the raised floors in use today. However, most are engineered to meet the concentrated uniform and rolling loads experienced in a typical workplace environment. Of issue is whether the plastic floor diffusers also meet these requirements. There have been some instances where the mounting rings did not hold up under constant use in heavy traffic. Today, there are some manufacturers who advertise fire-rated plastic diffusers. They fall in 3 categories: fire-rated plastic parts, non-fire-rated plastic parts protected by a metal enclosure, and fire-rated metal parts. The fire-rated plastics tend to be more brittle than the original non-fire-rated parts. The brittleness degrades the structural integrity of the diffuser, but more importantly, causes the mounting rings to break easily. Until and unless more plastic, less brittle, fire-rated plastics are developed, these should be avoided for use in floors where people may walk or sit. The non-fire-rated plastic diffusers with metal enclosures can be very difficult to install. The enclosures have to be mounted to the bottom of the floor tiles. These are normally irregular surfaces and sealing poses a great problem. Nailor Industries is the only manufacturer of cast aluminum, fully fire-rated floor diffuser parts for easy installation and safe sturdy operation.

Cleaning

Prior to the installation of the raised floor, the slab should be thoroughly cleaned and sealed. Cleaning the plenum at the end of construction is absolutely required. Regular cleaning on an annual basis along with local cleanup during plenum reconfiguration should suffice after occupation of the building. If some sort of a chemical spill or accident or fire causes plenum contamination, the accessibility of the underfloor plenum makes the process much simpler and more effective as compared to an overhead plenum.

Equipment Options

Perimeter Zones

Fan Coils

Since the perimeter zone has both a heating and a cooling requirement, 2-pipe or 4-pipe fan coils may be selected for perimeter equipment. Nailor's 38F units fit nicely between the floor pedestals and provide a variety of airflow ranges to satisfy any job requirement. Care must be taken in design to address noise issues with this equipment because the discharge fan noise may be exposed directly to the room with very little attenuation. Fan coils can be arranged for either constant volume air delivery or VAV delivery. Obviously, the VAV option is much more energy efficient. Primary air can be taken directly from the underfloor plenum or it can be ducted from above the floor in a heating mode. Some typical layouts are shown in Figures 9 through 14.

Fan coils can also be mounted in the ceiling return air plenum in the perimeter zone. They can be configured to take air directly from the return plenum in both the heating and cooling load reducing or eliminating the need for supply air ducts. See Figure 11.

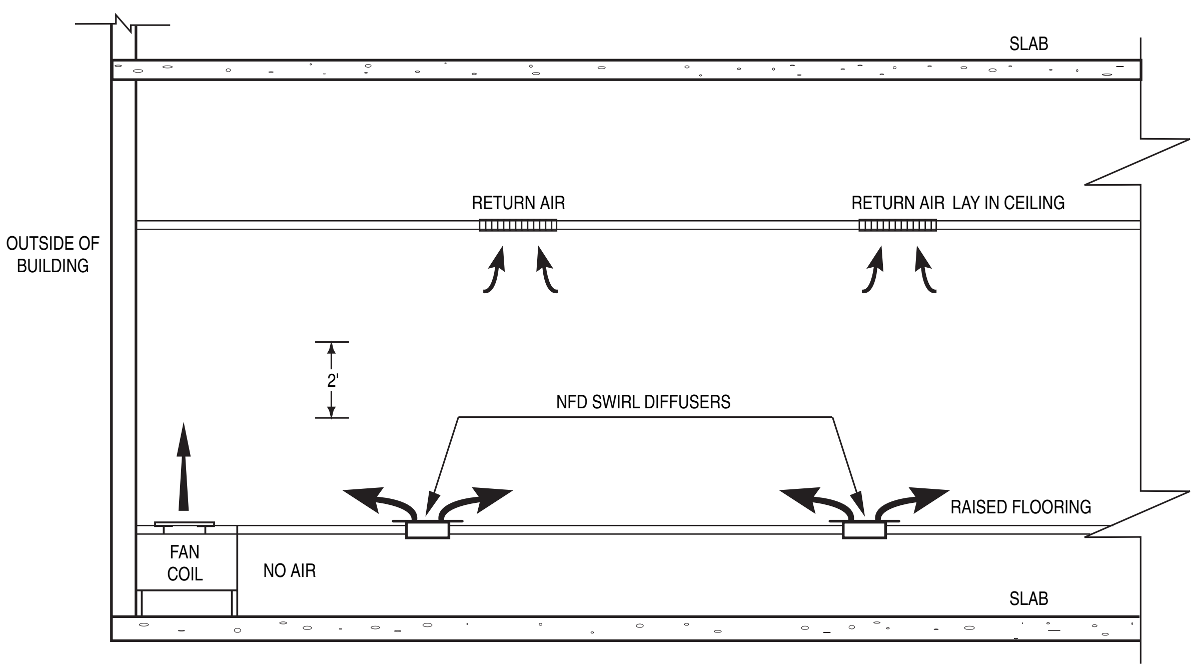


Figure 9:
Underfloor non-ducted fan coil

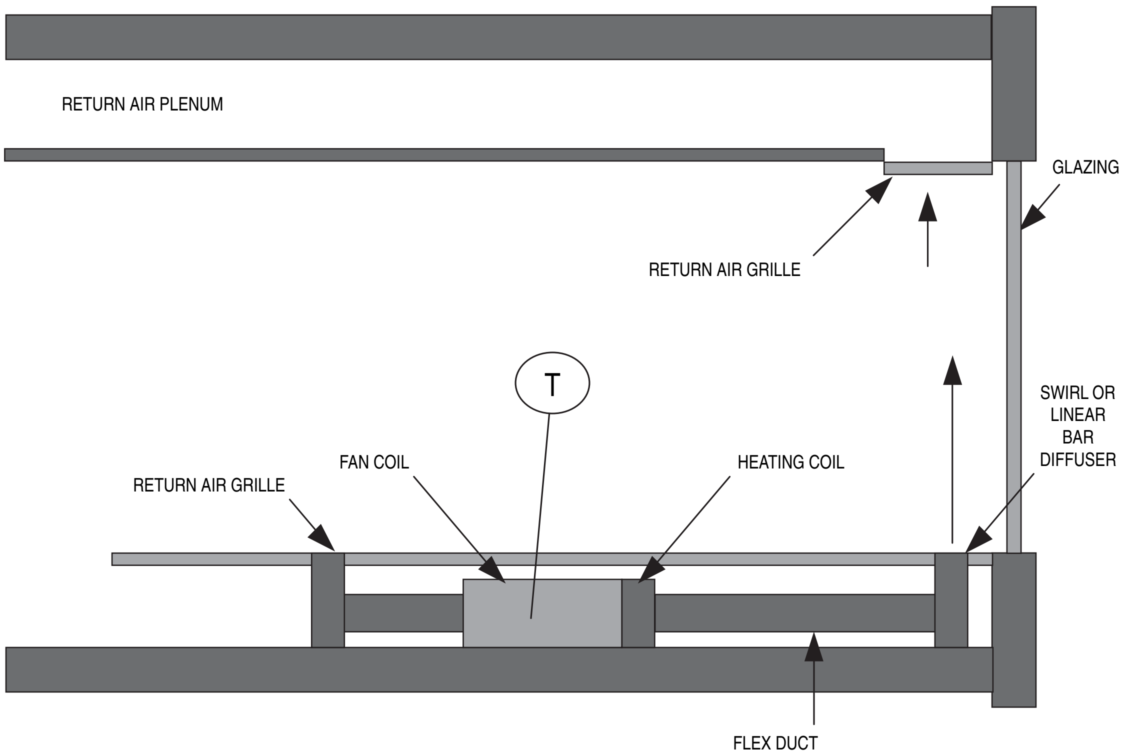


Figure 10:
Underfloor ducted fan coil

Fan coils can also be mounted in the ceiling return air plenum in the perimeter zone. They can be configured to take air directly from the return plenum in both the heating and cooling load reducing or eliminating the need for supply air ducts. See Figure 11.

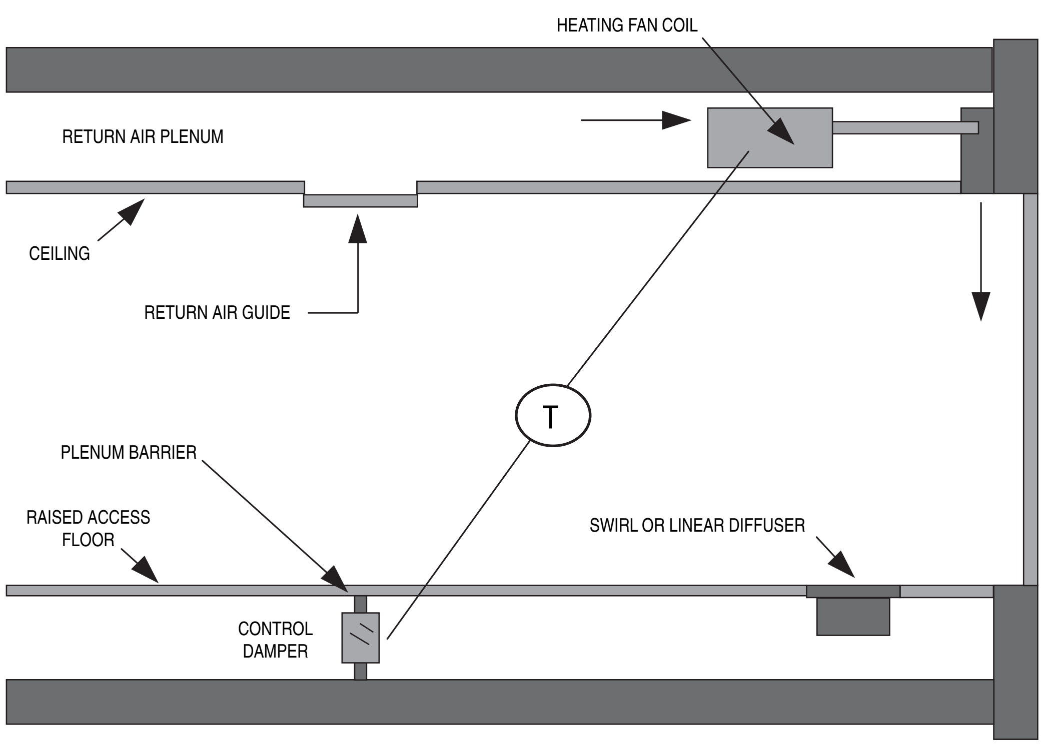


Figure 11:
Overhead fan coils

VAV or Fan Powered VAV Terminal Units

VAV or Fan Powered VAV Terminal Units can also be used for perimeter air distribution. Nailor's 38S units fit nicely between the floor pedestals and provide a variety of airflow ranges to satisfy any job requirement. Care must be taken in design to address noise issues with this equipment because the discharge fan noise may be exposed directly to the room with very little attenuation.

VAV terminal units can be arranged for either constant volume air delivery or VAV delivery. Obviously, the VAV option is much more energy efficient. Primary air can be taken directly from the underfloor plenum or it can be ducted from above the floor in a heating mode. Some typical layouts are shown in figures 9,10, and 12.

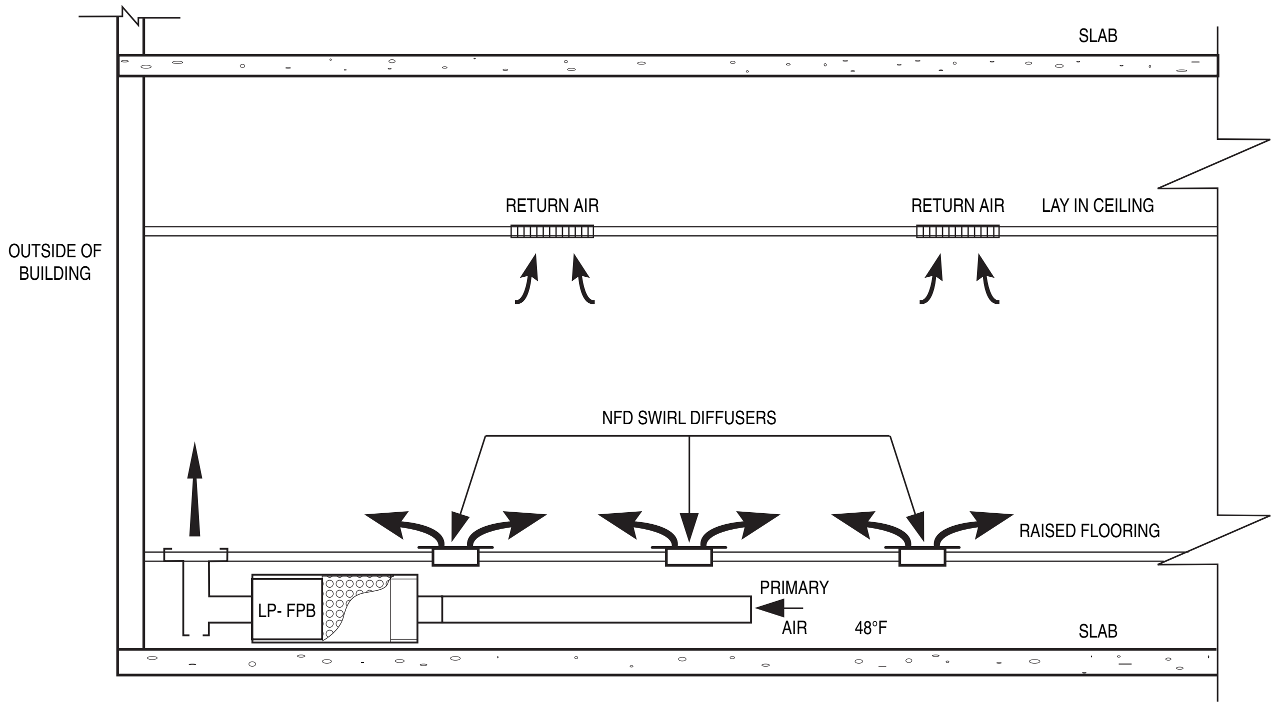


Figure 12:
Underfloor ducted fan powered VAV terminal unit

Fan powered VAV terminal units can also be employed above the ceiling in the perimeter zone. In cases of high envelope loads, the underfloor air may not be adequate to remove the perimeter heat. Using 55°F. (13°C.) or cooler air in the fan powered VAV terminal unit may be the only option in these circumstances. Primary air is ducted to the units and heat is supplied by the supplemental heaters, either electric or hot water, locally at the terminal units. See Figure 13.

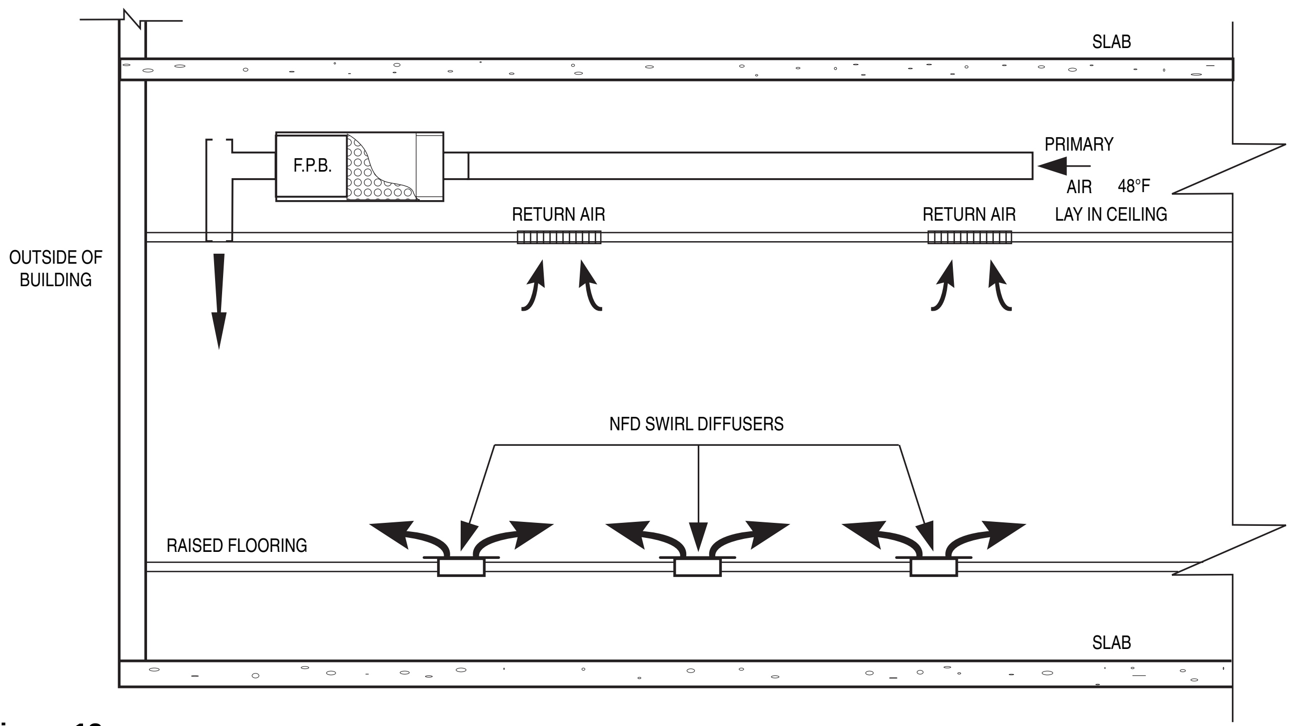


Figure 13:
Fan powered VAV terminal unit in ceiling

Conference Rooms

Conference rooms, training rooms and any other areas that are enclosed and subject to varying heat loads are usually designed with their own zone. These heat loads are much more dynamic as compared to an office area. Spaces like these should be served by some form of VAV control.

VAV Fan Coils or Fan Powered Terminal Units

When using a fan powered unit to supply the underfloor operating pressure under a conference or training room, the room will have to be isolated from the rest of the underfloor plenum by a septum or plenum divider. This septum will have to be sealed to the concrete floor and to the underside of the tiles that make up the raised floor. The fan powered unit is configured to pressurize the isolated plenum as shown in Figure 14. The VAV fan powered unit is equipped with an ECM motor for large turn down to handle large variations in loads. The motor controller will be controlled by a thermostat in the room and have at least P+I functionality to maintain efficacy of control and comfort in the space.

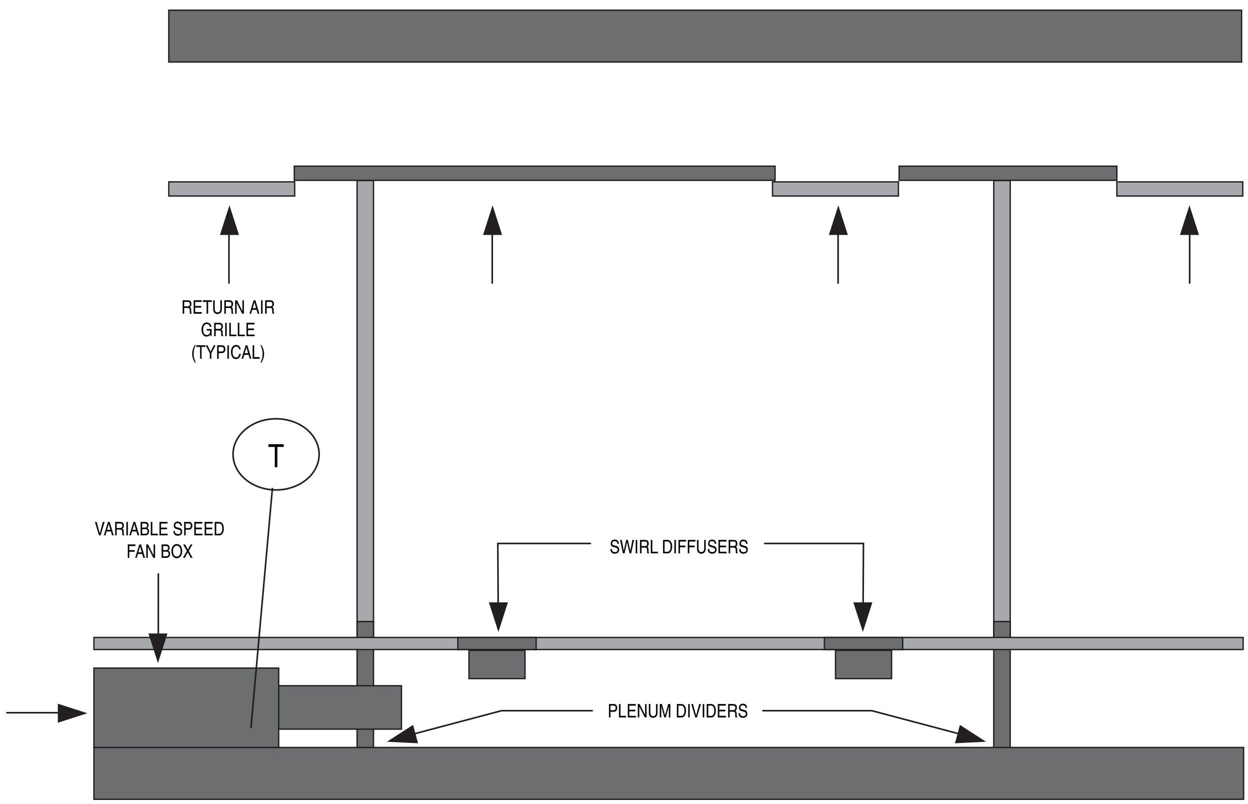


Figure 14:
Variable-speed fan terminal serving conference room.

VAV Diffusers

Another way to maintain room comfort with varying loads is to equip the room with VAV floor diffusers. Modulating diffusers can allow air from the primary plenum to increase or decrease to satisfy room demand. For conference rooms and training areas, the typical density of floor diffusers per square foot of space should be increased by at least 50% in order to provide for heavy heat loads during times of high occupancy. VAV diffusers have modulating actuators rather than 3 point floating devices to keep all the actuators in one zone synchronized. Actuators with 3 point floating control will become lost during the day and have to be recalibrated or zeroed regularly. The built-in actuator will be controlled by a thermostat in the room and have at least P+I functionality to maintain efficacy of control and comfort in the space.

Cost Issues

Addition of Raised Floor System		Further Addition of UFAD System	
Typical Cost Adds	**Typical Cost Reductions**	**Typical Cost Adds**	**Typical Cost Reductions**
Basic Structure Costs: • Increased column size to support floor • Mechanical cores must either be raised or (handicapped) ramping installed • Slab-to-slab height increase if space floor-to-ceiling height is to be maintained • Cost of the raised floor and premium for carpet tiles (vs. rolled carpet)	**Basic Structure Costs:** • No final slab leveling as floor is laser leveled	**Basic Structure Costs:** • Slab must be cleaned (and treated with an antimicrobial agent) prior to floor installation	**Basic Structure Costs:** • Slab-to-slab height may be reduced as HVAC equipment and ductwork is removed from the ceiling plenum • Removal of HVAC Equipment from overhead plenum may eliminate need for false ceiling.
Power/Voice/Data Service Costs:	**Power/Voice/Data Service Costs:** • Power wiring uses "homerun" power modules throughout the space to reduce cabling requirements • Floor outlet boxes in each workstation eliminate the need to electrify furniture • Modular plugs in outlet boxes reduce the required connection time for PVD services • Installation costs are reduced due to the ease of working at floor level • Conduit costs may be significantly reduced or eliminated if plenum rated cable is used	**Power/Voice/Data Service Costs:**	**Power/Voice/Data Service Costs:**
HVAC System Costs:	**HVAC System Costs:**	**HVAC System Costs:** • Thorough sealing of components/surfaces that compose the underfloor supply plenum • Addition of ducts or air highways to ensure proper delivery of the conditioned air through the underfloor plenum • Higher diffuser cost due to increased quantity and relatively higher cost ($/cfm) of the outlets • Additional smoke detectors for underfloor plenum • Special air handlers with bypass	**HVAC System Costs:** • Reduction (or elimination) of horizontal (branch) ductwork feeding terminal units • Reduction of (rectangular and flexible) discharge ductwork and dampers • Reduction of required thermal insulation as supply air passes through an already conditioned plenum • Reduced outlet balancing requirements as most diffusers allow occupant adjustment • Elimination of radiation dampers on supply outlets • Reduction in the number of required terminal units (especially in interior zones) • Reduced number of space thermostats and associated wiring as the number of terminal units are reduced • Potential reduction in return outlets if false ceiling is eliminated

Continued on Page F18 ....

....Continued

Addition of Raised Floor System		Further Addition of UFAD System (cont'd)	
Typical Cost Adds	**Typical Cost Reductions**	**Typical Cost Adds**	**Typical Cost Reductions**
HVAC System Costs:	**HVAC System Costs:**	**HVAC System Costs:**	**HVAC System Costs:** • Reduced installation costs as work is done at floor level • Possible reduction in air handling unit size and capacity (where design airflow quantity can be reduced)

Table 2a:
Cost Considerations for the Addition of Raised Floor and UFAD Systems: First Costs

Addition of Raised Floor System		Further Addition of UFAD System	
Typical Cost Adds	**Typical Cost Reductions**	**Typical Cost Adds**	**Typical Cost Reductions**
Utility Costs:	**Utility Costs:**	**Utility Costs:**	**Utility Costs:** • Reduced fan operational cost due to lower fan static pressures • Possible refrigeration plant operational cost savings due to increased chiller efficiency using warmer return water • Extended economizer cycle operation due to higher supply/return air temperatures
Maintenance/Operation Costs:	**Maintenance/Operation Costs:** • Reduced carpet replacement costs resulting from use of replaceable carpet tiles • Reduction of workstation relocation and/or service reconfiguration costs due to modular cabling and easily movable PVD service boxes	**Maintenance/Operation Costs:**	**Maintenance/Operation Costs:** • Reduced failures of control components due to reduction of terminal units • Reduced calls to maintenance regarding comfort complaints due to increased level of individual control
Cash Flow Related Intangibles:	**Cash Flow Related Intangibles:** • Possible accelerated depreciation on access floor and carpet (non-fixed assets)	**Cash Flow Related Intangibles:**	**Cash Flow Related Intangibles:** • Possible reduction in installation time of HVAC system reduces total construction time and enables earlier occupancy

Table 2b:
Cost Considerations for the Addition of Raised Floor and UFAD Systems: Life Cycle Costs

Standards, Codes and Ratings

ANSI/ASHRAE Standard 55-1992

UFAD systems usually involve some room stratification and greater temperature variations that are allowed in Standard 55-1992. The latest version, 1992, also allows for variances with individual control of the diffusers. While this can be used in Task Ambient systems, UFAD systems do not conform to Standard 55 allowable conditions as it is written today. There are efforts underway to update Standard 55-1992 to include UFAD designs.

ANSI/ASHRAE Standard 62-2001

Standard 62 provides guidelines for the determination of ventilation rates that will maintain acceptable indoor air quality. Currently, ventilation rates are adjustable based on the ventilation effectiveness Ev of the air distribution system. Displacement ventilation systems can actually provide ventilation effectiveness rates above 100%. UFAD systems are not explicitly addressed in Standard 62 at this time, although more definitive research is being promoted at ASHRAE to better define Ev for UFAD systems. Ev for UFAD systems is generally believed to be between 1.0 and 1.2.

Standard 62 requires minimum ventilation rates for different types of spaces. Some method of determining and insuring minimum ventilation rates must be provided in the design.

ANSI/ASHRAE/IESNA Standard 90.1-2001

There is potential conflicts under 90.1 concerning simultaneous heating and cooling to a common zone. In some designs where all occupants have individual control over their thermostats, it is possible for two individuals to set their respective thermostats such that one requires heating and the other cooling in the same zone. There are exceptions to the requirements of paragraph 9.5.2 in 90.1, and studying the subtle differences in operation between UFAD and overhead systems, may allow compliance for the UFAD design.

ANSI/ASHRAE Standard 113-1990

This is the only standard available for determining the air diffusion performance of a diffuser, and it is not applicable to underfloor systems. Current research is being sought to add procedures to the standard that will address UFAD systems.

ASHRAE Standard 129-1997

This is a test method for evaluating or rating an air distribution system's ability to provide ventilation air to a specific space in a building. Results from this test may be used to determine compliance with ASHRAE 62. Results for UFAD systems should allow credits that lead to reduced outdoor air requirements.

Title 24

Title 24 mandates off hour controls for central HVAC systems and stipulates that the largest zone that can be controlled in isolation is 25,000 square feet (2,300 m^2). Buildings with floor plates larger than this will have to be subdivided. Local fire codes may require even smaller zones.

Title 24 requires that zones with heating/cooling changeover designs have airflow reduced to 30% of peak before heating can commence. This means that perimeter zones served by fan powered units will have to require the fan powered units to modulate down to the 30% level before the heater can be energized. In perimeter zones that use some sort of baseboard heaters where the underfloor air is supplied by swirl diffusers, this may not be possible.

Title 24 prohibits electric heat; however, credits allowed under the improved chiller efficiency or enhanced airside economizer operation may allow its use.

Title 24 requires thermostatic controls with adjustable set points. Care should be taken in placing the thermostats to place them in representative locations. Because of the designed room stratification, typical locations may not be reasonable.

NFPA 90A

Paragraph 2-3.6.3.1 requires that diffusers that are mounted in the floor must have a dust basket supplied with the diffuser. For linear or bar diffusers located in perimeter plenums, an alternate means of dust collection must be provided since they do not come with dirt baskets. Furthermore diffusers must be supplied with a screen or grille that will not allow a 1/2" (1.3 cm) ball to pass through them.

Paragraph 2-3.6.2 and 2-3.7.2 state that diffusers "Shall be constructed of a non-combustible material or a material that has a maximum flame spread index of 25 and a maximum smoke developed index of 50."

Today, there are some manufacturers who advertise fire-rated plastic diffusers. They fall in 3 categories: fire-rated plastic parts, non-fire-rated plastic parts protected by a metal enclosure, and fire-rated metal parts. The fire-rated plastics tend to be more brittle than the original non-fire-rated parts. The brittleness degrades the structural integrity of the diffuser, but more importantly, causes the mounting rings to break easily. Until and unless more plastic, less brittle, fire-rated plastics are developed, these should be avoided for use in floors where people may walk or sit. The non-fire-rated plastic diffusers with metal enclosures can be very difficult to install. The enclosures have to be mounted to the bottom of the floor tiles. These are normally irregular surfaces and sealing poses a great problem. Nailor Industries is the only manufacturer of cast aluminum, fully fire-rated floor diffuser parts for easy installation and safe sturdy operation. Hence, only metal diffusers are truly acceptable for underfloor applications unless the local authority having jurisdiction over the fire codes specifically approves the plastic non-fire rated diffusers.

Uniform Building and Other Applicable Codes

Local fire codes may limit the size of a common underfloor plenum without smoke barriers. Sometimes they can be as small as 3000 ft^2 (280 m^2) or limited in width to 30 ft. (9 m).

Typically, underfloor plenums contain very low levels of combustible materials; however, some local codes require plenums under 18" (45 cm) to be sprinkled. Nearly all local codes require plenums over 18" (45 cm) to be sprinkled.

LEED

UFAD systems may garner LEED points in two categories: Energy and Atmosphere and Indoor Environmental Quality. Under Energy and Atmosphere, Credit 1 allows points for optimizing the energy performance of a building. Under Indoor Environmental Quality, Credit 2 allows points for Ev in excess of 0.9.

Design Issues

Floor Heights

There may be opportunities for lowering floor heights. Ceiling requirements should be reviewed carefully. If ceilings are eliminated, lighting and noise issues should be evaluated.

Underfloor Plenum Heights

Underfloor plenum heights are usually determined by the height of the largest equipment that must be fitted under the raised floor.

Space Cooling and Heating Loads

Loads are calculated just as they are with overhead systems. Attention must be paid to how successfully the floor diffusers will stratify the air in the occupied zone. Floor diffusers with high vertical projections are not going to effectively set up the required thermocline in the room. This in turn will require that enough airflow be supplied to the zone to mix the entire room. Floor diffusers such as Nailor's swirl diffusers will establish a thermocline at the lowest allowable level and reduce airflow requirements into the room to similar levels as used in traditional overhead systems.

The resultant lower airflow requirement is the result of the stratification above the occupied zone and the divergence of the room load from the total equipment load. Since air is rising at it warms in the homogeneous occupied zone, much of the heat is being moved out of the room from the stratified unoccupied zone without affecting the actual room load. Heat gains in the unoccupied zone are not room loads. See figure 4 and Table 3 for a guide to radiant and convective heating splits.

Heat Source	Radiant Portion [%]	Convective Portion [%]
Transmitted solar, no inside shade	100	0
Window solar, with inside shade	63	37
Absorbed (by fenestration) solar	63	37
Fluorescent lights, suspended, unvented	67	33
Fluorescent lights, recessed, vented to return air	59	41
Fluorescent lights, recessed, vented to return air and supply air	19	81
Incandescent lights	80	20
People, moderate office work	38	62
Conduction, exterior walls	63	37
Conduction, exterior roof	84	16
Infiltration and ventilation	0	100
Machinery and applicances	20 to 80	80 to 20

Table 3:
Radiant/Convective Splits for Typical Office Heat Sources

Space heating is normally only needed near the perimeter of the building where the heat loss to the outside of the building needs to be offset. Sometimes top floors during periods of low occupancy like at night or weekends will need a small amount of heating also. Load calculations for heating are the same as for overhead heating. If return air can be injected into the perimeter zone for heating use, system efficiency can be greatly improved.

The building envelope has the largest loads in the building since they are affected by rapid climate fluctuations and excursions to peaks for extended periods. The purposes of the perimeter system are to neutralize the skin loads, provide heating and cooling as needed, and provide automatic control to allow quick response to potentially rapid load changes. Neutralizing the skin loading allows the isolation of the perimeter zone from the interior zone. Perimeter zones are normally 15 feet or less in depth. Some are as thin as two feet depending on air distribution design.

Locations of Floor Diffusers

Swirl diffusers are typically used in the interior zone. The flexibility of locating the swirl diffusers in the common underfloor plenum is a big plus to UFAD systems. The diffusers can be located in close proximity to the space loads with ease. Typically, one diffuser is located in each cubicle allowing direct adjustment by the occupant. In non divided areas, one diffuser in every 80 to 110 square feet is normally adequate for typical office loads. Conference and training rooms will usually require an increase in diffusers to one for each 50 to 75 square feet.

Perimeter zones are usually served by linear bar grilles. These grilles provide a smooth curtain of air that can sweep up the wall and help to isolate the skin loads on the building. Care must be taken to limit the throw on these devices to 5 to 8 feet. Longer throws will curl back into the room in heating modes and disturb the thermocline in the interior zones.

Useful Formulas and Definitions

Airflow

Q = V x A
Q = Airflow Rate, cfm (l/s)
V = Velocity, fpm (m/s)
A = Area, ft² (m²)

Pressure

Imperial Units

$$VP\ (\text{" w.g.}) = \left(\frac{V\ (fpm)}{4005}\right)^2$$

Metric Units

$$VP\ (Pa) = \left(\frac{V\ (m/s)}{1.3}\right)^2$$

VP = Velocity Pressure

TP = SP + VP
TP = Total Pressure, " w.g. (Pa)
SP = Static Pressure, " w.g. (Pa)

Heat Transfer

Imperial Units	Metric Units
H = 1.085 x cfm x Δt (°F)	H= 1.23 x l/s x Δt (°C)
H = Heat Transfer, Btu's/hr.	H = Heat Transfer, watts

Btu = British Thermal Unit
Δt = Temp. Differential

Water Coils

Imperial Units

$$\Delta t(°F) = 927 \times \frac{Mbh}{cfm}$$

Metric Units

$$\Delta t\ (°C) = 829 \times \frac{kW}{l/s}$$

Δt = Air Temperature Rise
Mbh = 1000's of Btu's/hr.

$$\Delta t(°F) = 2.04 \times \frac{Mbh}{GPM} \qquad \Delta t\ (°C) = 0.244 \times \frac{kW}{l/s}$$

Δt = Water Temperature Drop
GPM = Water Flow, gallons per minute
l/s = Liters per second

Electric Coils

$$\Delta t(°F) = \frac{kW \times 3160}{cfm}$$

$$kW = \frac{cfm \times \Delta t}{3160}$$

Δt = Air Temperature Rise
kW = Kilowatts

Power DC Circuits

$$hp = \frac{E \times I \times Eff.}{746}$$

W = E x I

$$Eff. = \frac{746 \times bhp}{W}$$

Power AC Circuits (Single Phase)

$$PF = \frac{W}{E \times I}$$

$$I = \frac{746 \times hp}{E \times Eff. \times PF}$$

$$Eff. = \frac{746 \times hp}{E \times I \times PF}$$

$$kW = \frac{E \times I \times PF \times Eff.}{1000}$$

$$hp = \frac{E \times I \times PF \times Eff.}{746}$$

$$kVA = \frac{I \times E}{1000}$$

Power AC Circuits (Three Phase)

$$PF = \frac{W}{E \times I \times 1.732}$$

$$I = \frac{746 \times hp}{1.732 \times E \times PF \times Eff.}$$

$$Eff. = \frac{746 \times hp}{E \times I \times PF \times 1.732}$$

$$kW = \frac{E \times I \times PF \times 1.732}{1000}$$

$$hp = \frac{E \times I \times 1.732 \times PF \times Eff.}{746}$$

$$kVA = \frac{1.732 \times I \times E}{1000}$$

PF = Power Factor
W = Watts
E = Volts
I = Amperes
hp = Horsepower
Eff. = Efficiency

Imperial/Metric Guide Conversion Factors

Quantity	Imperial Unit	Metric Unit		From Imperial To Metric Multiply By:	From Metric To Imperial Multiply By:
Area	square foot	square meter	(m^2)	0.0929	10.764
	square inch	square millimeter	(mm^2)	645.16	.00155
Density	pounds per cubic foot	kilograms per cubic meter	(kg/M^3)	16.018	.0624
Energy	British thermal unit (BTU)	joule	(J)	1055.056	.000948
	kilowatt hour	megajoule	(MJ)	3.6	.2778
	watts per second	joule	(J)	1.0	1.0
	horsepower hour	megajoule	(MJ)	2.6845	.3725
Force	ounce force	newton	(N)	.278	3.597
	pound force	newton	(N)	4.4482	.2248
	kilogram force	newton	(N)	9.8067	.102
Heat	BTU per hour	watt	(W)	.2931	3.412
	BTU per pound	joules per kilogram	(J/kg)	2326.0	.00043
Length	inch	millimeter	(mm)	25.4	.0394
	foot	millimeter	(mm)	304.8	.00328
	foot	meter	(m)	.3048	3.2808
	yard	meter	(m)	.9144	1.0936
Mass (weight)	ounce (avoirdupois)	gram	(g)	28.350	.0353
	pound (avoirdupois)	kilogram	(kg)	.4536	2.2046
Power	horsepower	kilowatt	(kW)	.7457	1.341
	horsepower (boiler)	kilowatt	(kW)	9.8095	.1019
	foot pound - force per minute	watt	(W)	.0226	44.254
	ton of refrigeration	kilowatt	(kW)	3.517	.2843
Pressure	inch of water column	kilopascal	(kPa)	.2486	4.0219
	foot of water column	kilopascal	(kPa)	2.9837	.3352
	inch of mercury column	kilopascal	(kPa)	3.3741	.2964
	ounces per square inch	kilopascal	(kPa)	.4309	2.3206
	pounds per square inch	kilopascal	(kPa)	6.8948	.145
Temperature	Fahrenheit	Celsius	(°C)	5/9(°F-32)	(9/5°C)+32
Torque	ounce - force inch	millinewton-meter	(mN.m)	7.0616	.1416
	pound - force inch	newton-meter	(N.m)	.1130	8.8495
	pound - force foot	newton-meter	(N.m)	1.3558	.7376
Velocity	feet per second	meters per second	(m/s)	.3048	3.2808
	feet per minute	meters per second	(m/s)	.00508	196.85
	miles per hour	meters per second	(m/s)	.44704	2.2369
Volume (capacity)	cubic foot	liter	(l)	28.3168	.03531
	cubic inch	cubic centimeter	(cm^2)	16.3871	.06102
	cubic yard	cubic meter	(m^3)	.7646	1.308
	gallon (U.S.)	liter	(l)	3.785	.2642
	gallon (imperial)	liter	(l)	4.546	.2120
Volume (flow)	cubic feet per minute (cfm)	liters per second	(l/s)	.4719	2.119
	cubic feet per minute (cfm)	cubic meters per second	(m^3/s)	.0004719	2119.0
	cubic feet per hour (cfh)	milliliters per second	(ml/s)	7.8658	.127133
	gallons per minute (U.S.)	liters per second	(l/s)	.06309	15.850
	gallons per minute (imperial)	liters per second	(l/s)	0.7577	13.198

Pressure Measurement

Concepts of Pressure. Pressure is force per unit area. This may also be defined as energy per unit volume of fluid. There are three categories of pressure — Total Pressure, Static Pressure and Velocity Pressure. They are all associated with air handling. Unit of pressure is expressed in inches of water, designated **in. w.g.**

Static Pressure is the normal force per unit area at a small hole in the wall of a duct or other boundaries. It is a function of air density and degree of compression. It may be thought of as the pressure in a tire or in a balloon which extends in all directions.

Velocity Pressure is the force per unit area capable of causing an equivalent velocity in moving air. Velocity pressure is a function of air density and velocity. At standard air density, the relationship between velocity pressure and velocity is expressed in the following formula:

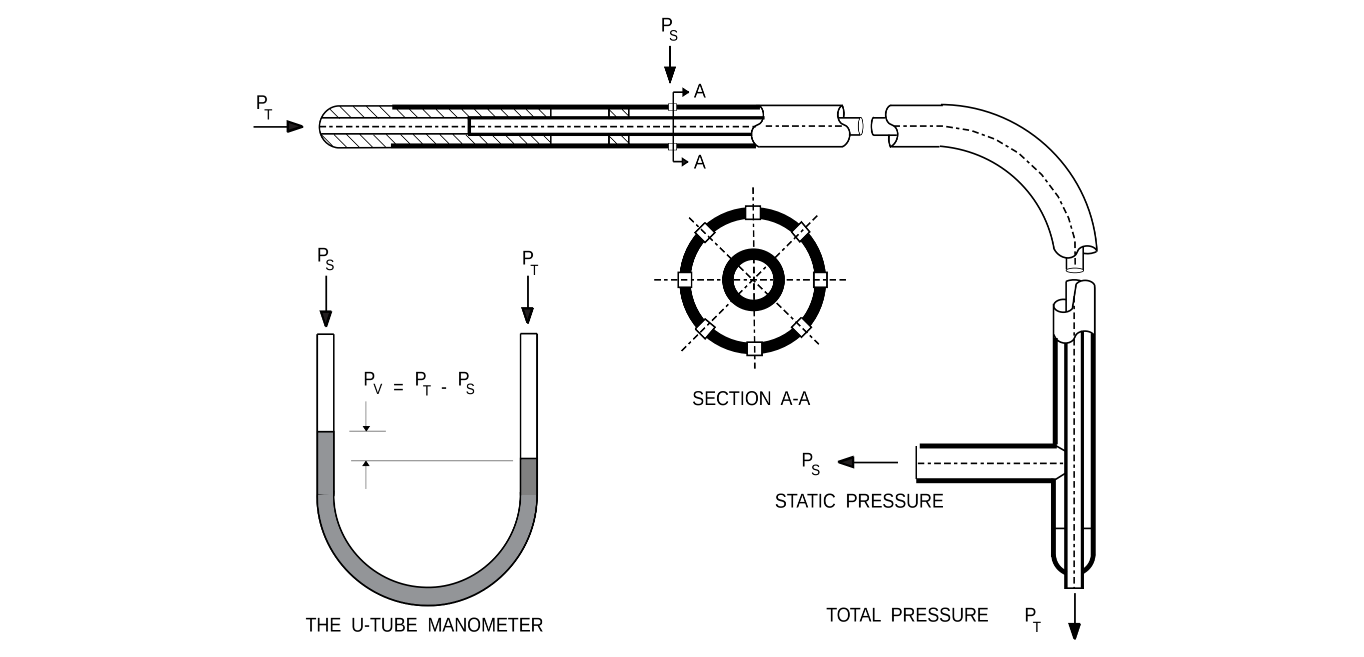
$$Pv = \left(\frac{V}{4005}\right)^2 \text{ or } V = 4005\sqrt{Pv}$$

Where: V = Air Velocity (FPM)
Pv = Velocity Pressure (in. w.g.)

Total Pressure, as its name implies, is the sum of static pressure and velocity pressure.

The Pitot Static Tube is an instrument used to measure pressure and velocities as illustrated below. It is constructed of two tubes. The inner, or impact tube, senses the total pressure as the impact opening faces upstream. The outer tube senses only the static pressure, which communicates with the airstream through small holes in its wall.

The U-Tube Manometer connects both parts of the Pitot Static Tube. The manometer functions as a subtracting device to give a reading of velocity pressure.



CONVERSION CHART for converting *VELOCITY PRESSURE* in inches of water to *VELOCITY* in feet per minute

Note: This chart is based upon standard air conditions of 70° Fahrenheit and 29.92 inches of mercury (barometric pressure), and assumes that the airflow is essentially non-compressible (under 10 inches of water pressure); as reflected by the following formula.

$$\text{Velocity (fpm)} = 4005 \sqrt{\text{Velocity Pressure in inches of water}}$$

VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V
.001”	127	.062”	996	.123”	1404	.184”	1718	.245”	1982	.306”	2215	.367”	2426	.77”	3514	1.38”	4705	1.99”	5651	2.60”	6458
.002”	179	.063”	1004	.124”	1410	.185”	1723	.246”	1987	.307”	2219	.368”	2429	.78”	3537	1.39”	4722	2.00”	5664	2.61”	6470
.003”	219	.064”	1012	.125”	1416	.186”	1727	.247”	1991	.308”	2223	.369”	2433	.79”	3560	1.40”	4739	2.01”	5678	2.62”	6482
.004”	253	.065”	1020	.126”	1422	.187”	1732	.248”	1995	.309”	2226	.370”	2436	.80”	3582	1.41”	4756	2.02”	5692	2.63”	6495
.005”	283	.066”	1029	.127”	1427	.188”	1737	.249”	1999	.310”	2230	.371”	2439	.81”	3604	1.42”	4773	2.03”	5706	2.64”	6507
.006”	310	.067”	1037	.128”	1433	.189”	1741	.250”	2003	.311”	2233	.372”	2443	.82”	3625	1.43”	4790	2.04”	5720	2.65”	6519
.007”	335	.068”	1045	.129”	1439	.190”	1746	.251”	2007	.312”	2236	.373”	2445	.83”	3657	1.44”	4806	2.05”	5734	2.66”	6532
.008”	358	.069”	1052	.130”	1444	.191”	1750	.252”	2011	.313”	2239	.374”	2449	.84”	3669	1.45”	4823	2.06”	5748	2.67”	6544
.009”	380	.070”	1060	.131”	1449	.192”	1755	.253”	2015	.314”	2242	.375”	2453	.85”	3690	1.46”	4840	2.07”	5762	2.68”	6556
.010”	400	.071”	1067	.132”	1455	.193”	1759	.254”	2019	.315”	2245	.376”	2456	.86”	3709	1.47”	4856	2.08”	5776	2.69”	6569
.011”	420	.072”	1075	.133”	1461	.194”	1764	.255”	2023	.316”	2248	.377”	2459	.87”	3729	1.48”	4873	2.09”	5790	2.70”	6581
.012”	439	.073”	1082	.134”	1466	.195”	1768	.256”	2027	.317”	2251	.378”	2462	.88”	3758	1.49”	4889	2.10”	5804	2.71”	6593
.013”	457	.074”	1089	.135”	1471	.196”	1773	.257”	2031	.318”	2254	.379”	2466	.89”	3779	1.50”	4905	2.11”	5817	2.72”	6605
.014”	474	.075”	1097	.136”	1477	.197”	1777	.258”	2035	.319”	2257	.380”	2469	.90”	3800	1.51”	4921	2.12”	5831	2.73”	6617
.015”	491	.076”	1104	.137”	1482	.198”	1782	.259”	2039	.320”	2260	.381”	2472	.91”	3821	1.52”	4938	2.13”	5845	2.74”	6629
.016”	507	.077”	1111	.138”	1488	.199”	1787	.260”	2042	.321”	2264	.382”	2475	.92”	3842	1.53”	4954	2.14”	5859	2.75”	6641
.017”	522	.078”	1119	.139”	1493	.200”	1791	.261”	2046	.322”	2268	.383”	2479	.93”	3863	1.54”	4970	2.15”	5872	2.76”	6654
.018”	537	.079”	1125	.140”	1498	.201”	1795	.262”	2050	.323”	2272	.384”	2481	.94”	3884	1.55”	4986	2.16”	5886	2.77”	6666
.019”	552	.080”	1133	.141”	1504	.202”	1800	.263”	2054	.324”	2276	.385”	2485	.95”	3904	1.56”	5002	2.17”	5899	2.78”	6678
.020”	566	.081”	1140	.142”	1509	.203”	1804	.264”	2058	.325”	2280	.386”	2488	.96”	3924	1.57”	5018	2.18”	5913	2.79”	6690
.021”	580	.082”	1147	.143”	1515	.204”	1809	.265”	2062	.326”	2284	.387”	2491	.97”	3945	1.58”	5034	2.19”	5927	2.80”	6702
.022”	594	.083”	1154	.144”	1520	.205”	1813	.266”	2066	.327”	2289	.388”	2495	.98”	3965	1.59”	5050	2.20”	5940	2.81”	6714
.023”	607	.084”	1161	.145”	1525	.206”	1818	.267”	2070	.328”	2293	.389”	2499	.99”	3985	1.60”	5066	2.21”	5954	2.82”	6725
.024”	620	.085”	1167	.146”	1530	.207”	1822	.268”	2074	.329”	2297	.390”	2501	1.00”	4005	1.61”	5082	2.22”	5967	2.83”	6737
.025”	633	.086”	1175	.147”	1536	.208”	1827	.269”	2078	.330”	2301	.40”	2533	1.01”	4025	1.62”	5098	2.23”	5981	2.84”	6749
.026”	645	.087”	1181	.148”	1541	.209”	1831	.270”	2081	.331”	2304	.41”	2563	1.02”	4045	1.63”	5114	2.24”	5994	2.85”	6761
.027”	658	.088”	1188	.149”	1546	.210”	1835	.271”	2085	.332”	2308	.42”	2595	1.03”	4064	1.64”	5129	2.25”	6008	2.86”	6773
.028”	670	.089”	1193	.150”	1551	.211”	1839	.272”	2089	.333”	2311	.43”	2626	1.04”	4084	1.65”	5144	2.26”	6021	2.87”	6785
.029”	682	.090”	1201	.151”	1556	.212”	1844	.273”	2093	.334”	2315	.44”	2656	1.05”	4103	1.66”	5160	2.27”	6034	2.88”	6797
.030”	694	.091”	1208	.152”	1561	.213”	1848	.274”	2097	.335”	2318	.45”	2687	1.06”	4123	1.67”	5175	2.28”	6047	2.89”	6809
.031”	705	.092”	1215	.153”	1567	.214”	1853	.275”	2101	.336”	2322	.46”	2716	1.07”	4142	1.68”	5191	2.29”	6060	2.90”	6820
.032”	716	.093”	1222	.154”	1572	.215”	1857	.276”	2105	.337”	2325	.47”	2746	1.08”	4162	1.69”	5206	2.30”	6074	2.91”	6832
.033”	727	.094”	1228	.155”	1577	.216”	1862	.277”	2119	.338”	2329	.48”	2775	1.09”	4181	1.70”	5222	2.31”	6087	2.92”	6844
.034”	738	.095”	1234	.156”	1582	.217”	1866	.278”	2113	.339”	2332	.49”	2804	1.10”	4200	1.71”	5237	2.32”	6100	2.93”	6855
.035”	749	.096”	1241	.157”	1587	.218”	1870	.279”	2116	.340”	2335	.50”	2832	1.11”	4219	1.72”	5253	2.33”	6113	2.94”	6867
.036”	759	.097”	1247	.158”	1592	.219”	1875	.280”	2119	.341”	2338	.51”	2860	1.12”	4238	1.73”	5268	2.34”	6126	2.95”	6879
.037”	770	.098”	1254	.159”	1597	.220”	1879	.281”	2123	.342”	2342	.52”	2888	1.13”	4257	1.74”	5283	2.35”	6139	2.96”	6890
.038”	780	.099”	1260	.160”	1602	.221”	1883	.282”	2127	.343”	2345	.53”	2916	1.14”	4276	1.75”	5298	2.36”	6152	2.97”	6902
.039”	791	.100”	1266	.161”	1607	.222”	1887	.283”	2131	.344”	2349	.54”	2943	1.15”	4295	1.76”	5313	2.37”	6165	2.98”	6913
.040”	801	.101”	1273	.162”	1612	.223”	1892	.284”	2135	.345”	2352	.55”	2970	1.16”	4314	1.77”	5328	2.38”	6179	2.99”	6925
.041”	811	.102”	1279	.163”	1617	.224”	1896	.285”	2139	.346”	2356	.56”	2997	1.17”	4332	1.78”	5343	2.39”	6191	3.00”	6937
.042”	821	.103”	1285	.164”	1622	.225”	1900	.286”	2143	.347”	2360	.57”	3024	1.18”	4350	1.79”	5359	2.40”	6204	3.01”	6948
.043”	831	.104”	1292	.165”	1627	.226”	1905	.287”	2147	.348”	2363	.58”	3050	1.19”	4368	1.80”	5374	2.41”	6217	3.02”	6960
.044”	840	.105”	1298	.166”	1632	.227”	1909	.288”	2151	.349”	2366	.59”	3076	1.20”	4386	1.81”	5388	2.42”	6230	3.03”	6971
.045”	849	.106”	1304	.167”	1637	.228”	1913	.289”	2154	.350”	2369	.60”	3102	1.21”	4405	1.82”	5403	2.43”	6243	3.04”	6983
.046”	859	.107”	1310	.168”	1642	.229”	1917	.290”	2157	.351”	2372	.61”	3127	1.22”	4423	1.83”	5418	2.44”	6256	3.05”	6994
.047”	868	.108”	1316	.169”	1646	.230”	1921	.291”	2161	.352”	2376	.62”	3153	1.23”	4442	1.84”	5433	2.45”	6269	3.06”	7006
.048”	877	.109”	1322	.170”	1651	.231”	1925	.292”	2164	.353”	2379	.63”	3179	1.24”	4460	1.85”	5447	2.46”	6281	3.07”	7017
.049”	887	.110”	1328	.171”	1656	.232”	1929	.293”	2168	.354”	2383	.64”	3204	1.25”	4478	1.86”	5462	2.47”	6294	3.08”	7028
.050”	896	.111”	1334	.172”	1661	.233”	1933	.294”	2171	.355”	2386	.65”	3229	1.26”	4495	1.87”	5477	2.48”	6307	3.09”	7040
.051”	904	.112”	1340	.173”	1666	.234”	1937	.295”	2175	.356”	2389	.66”	3254	1.27”	4513	1.88”	5491	2.49”	6319	3.10”	7051
.052”	913	.113”	1346	.174”	1670	.235”	1941	.296”	2179	.357”	2393	.67”	3279	1.28”	4531	1.89”	5506	2.50”	6332	3.11”	7063
.053”	922	.114”	1352	.175”	1675	.236”	1945	.297”	2182	.358”	2396	.68”	3303	1.29”	4549	1.90”	5521	2.51”	6345	3.12”	7074
.054”	931	.115”	1358	.176”	1680	.237”	1950	.298”	2186	.359”	2400	.69”	3327	1.30”	4566	1.91”	5535	2.52”	6358	3.13”	7085
.055”	939	.116”	1364	.177”	1685	.238”	1954	.299”	2189	.360”	2403	.70”	3351	1.31”	4583	1.92”	5550	2.53”	6370	3.14”	7097
.056”	948	.117”	1370	.178”	1690	.239”	1958	.300”	2193	.361”	2406	.71”	3375	1.32”	4601	1.93”	5564	2.54”	6383	3.15”	7108
.057”	956	.118”	1376	.179”	1695	.240”	1962	.301”	2197	.362”	2410	.72”	3398	1.33”	4619	1.94”	5579	2.55”	6395	3.16”	7119
.058”	964	.119”	1382	.180”	1699	.241”	1966	.302”	2200	.363”	2413	.73”	3422	1.34”	4636	1.95”	5593	2.56”	6408	3.17”	7131
.059”	973	.120”	1387	.181”	1704	.242”	1970	.303”	2204	.364”	2416	.74”	3445	1.35”	4653	1.96”	5608	2.57”	6420	3.18”	7142
.060”	981	.121”	1393	.182”	1709	.243”	1974	.304”	2208	.365”	2420	.75”	3468	1.36”	4671	1.97”	5623	2.58”	6433	3.19”	7153
.061”	989	.122”	1399	.183”	1713	.244”	1978	.305”	2212	.366”	2423	.76”	3491	1.37”	4688	1.98”	5637	2.59”	6445	3.20”	7164

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