energy design resources

design brief

UNDERFLOOR AIR DISTRIBUTION AND ACCESS FLOORS

Underfloor air distribution and access floor systems can provide energy savings, improved indoor air quality, and a technology ready environment for today's commercial buildings.

Summary

Underfloor air distribution and access floor systems provide numerous advantages to commercial building owners and occupants compared to traditional overhead air distribution systems with "pipe and wire" data, telecommunications, and electrical distribution systems. Underfloor air systems can provide energy savings while improving comfort and indoor air quality in many applications. The additional costs of the access floor system are partially offset by savings in wiring and HVAC installation costs. In buildings where frequent remodeling is required, savings in remodeling costs alone can easily pay for the system. Improvements in occupant health and comfort due to improved indoor air quality can increase employee productivity and company profitability. This design brief is an introduction to underfloor air and access floor systems, and addresses the following topics:

- Displacement ventilation and hybrid underfloor systems
- Energy savings and indoor air quality improvement
- Access floor system design and construction
- Economics of combined underfloor air and access floor systems
- Comfort and productivity issues
- Applications of underfloor air and access floor systems

CONTENTS

Buildings designed with underfloor air distribution and access floor systems can offer the enhanced level of energy efficiency, comfort, productivity, flexibility, and improved infrastructure demanded by building owners and occupants in today's market.

Introduction

What Is Underfloor Air Distribution?

Underfloor air distribution systems are a general class of air distribution systems that deliver air through diffusers in the floor, with the intent of maintaining comfort and indoor air quality levels only in the occupied lower portion of space. These systems are increasingly popular alternatives to the traditional overhead, or "fully-mixed" systems, which attempt to condition the air in the whole volume of space. Underfloor systems provide unique opportunities for energy savings, enhanced comfort control, and improved indoor air quality.

What Is an Access Floor?

An access floor is a modular system of architectural floor panels installed on pedestals above the structural floor to create an easily accessible underfloor space. Traditionally, access floor systems have been widely used in clean rooms and in spaces with large amounts of electronic equipment, such as control rooms and computer rooms. With the arrival of the technologically laden office environment, demand for access floors is rising rapidly. Owners need their buildings to be "technology-ready," with ample power, voice, and data services that are easily accessible and reconfigurable.

Why Are These Systems Important to Building Designers and Owners?

Underfloor air distribution can provide better comfort, higher indoor air quality, and lower energy costs. An access floor system provides flexibility in space management as well as easy maintenance of power, voice, and data wiring. Integrating the underfloor air distribution system with the access floor creates the opportunity for better management of communications and data infrastructure with improved HVAC. This synergistic combination of building systems gives the building owner an integrated design solution that can provide a substantial return on investment over the life of the building.

Underfloor Air Distribution

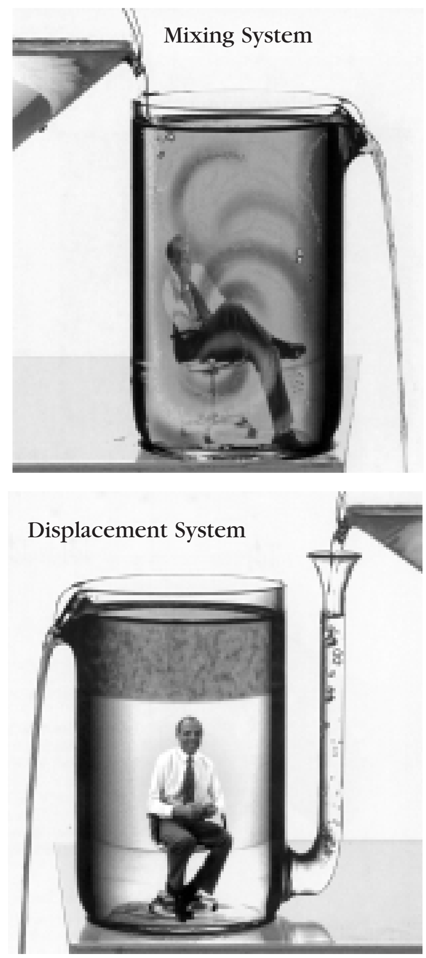
Underfloor air distribution systems introduce air at the floor level, with return grilles located near the ceiling. The space is divided into two zones, an occupied zone extending from the floor to head level, and an unoccupied zone extending from the top of the occupied zone to the ceiling. The systems are designed to condition the lower occupied zone only; temperature conditions in the upper zone are allowed to float above normal comfort ranges. To avoid occupant discomfort, air is introduced into the space between 65°F and 68°F.

In contrast, traditional overhead ventilation systems supply and return air at the ceiling. The system produces a large single zone of fully-mixed, room-temperature air. Using a liquid and beaker analogy, **Figure 1** is a simplified illustration of the difference between an underfloor system and a conventional fully-mixed system. In the underfloor system, cool liquid introduced from below flows through the occupied zone, picking up heat and contaminants and pushing them into the unoccupied zone above. In the fully-mixed system, cooler liquid delivered from above mixes with all the liquid to maintain a constant temperature throughout the beaker. This dilutes contaminants but does not effectively purge them.

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

Figure 1: Underfloor ventilation beaker analogy

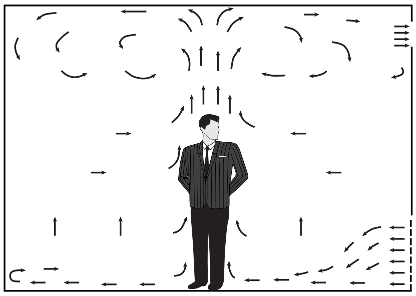
The upper figure shows a beaker filled and emptied from the top, much like an overhead mixed ventilation system. The lower figure shows a beaker filled with cool water from the bottom, with warm water exiting from the top.



Source: Healthy Buildings International

Figure 2: Displacement ventilation airflow

In a displacement ventilation system, cool air pools on the floor and rises slowly as it picks up heat. Heat sources create plumes that improve air circulation.



Source: Architectural Energy Corporation

Displacement Ventilation

Displacement ventilation systems deliver air at floor level into the space at very low velocity, typically less than 50 feet per minute (fpm). At this velocity, the air coming out of the diffuser can barely be felt, and the fresh air "pools" onto the floor. The system produces two distinct zones of air, one characterized by stratified layers of relatively cool and fresh air, the other by fairly uniform hot and stale air. The vertical flow profile in the lower zone can be generally described as upward laminar flow, or "plug flow." The effect of the plug flow is to displace the hot stale air into an area well above the breathing level of the occupants, giving occupants the benefit of breathing significantly higher-quality air. The displacement effect is augmented by the presence of heat sources within the occupied space, as shown in **Figure 2**. The thermal plume created by a heat source has the effect of enhancing the airflow around the source, thereby improving overall heat removal. The plume is inherently advantageous in applications where air contaminants and heat are linked to the same source.

Draft is usually not an issue in spaces served by displacement ventilation systems, but the temperature difference between the floor and head levels (the temperature gradient) is an important design issue. Displacement ventilation systems are generally applied to spaces that require cooling during occupied hours. They do not function well as heating systems; when heating is required, it is generally supplied by a separate system. Conventional European design practice limits the use of displacement ventilation systems to spaces with peak cooling loads of 12 Btu/hr-ft^2 or less. In spaces with higher cooling loads, radiant cooling systems are used in combination with displacement ventilation. Recent U.S. research suggests that displacement ventilation systems can be applied to spaces with cooling loads up to 38 Btu/hr-ft^2.[1]

Hybrid Underfloor System

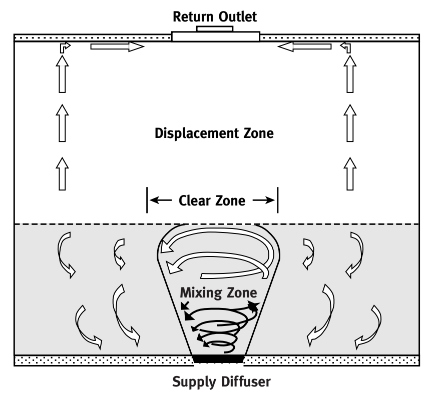
The second general type of underfloor air distribution system can be characterized as a hybrid underfloor system, a combination of displacement ventilation and conventional mixing systems. Like the displacement ventilation system, the hybrid underfloor system attempts to condition only the occupied lower portion of space, producing two distinct zones of air, one cool and relatively fresh, the other hot and stale. Unlike the displacement ventilation system, however, the hybrid underfloor system aims to reduce the stratification in the occupied lower portion by delivering air at higher velocity (200 to 400 fpm). This results in a more mixed and turbulent vertical flow profile and a smaller temperature gradient. While hybrid underfloor systems may more or less reduce the comfort problems associated with an excessive temperature gradient, they usually create small subzones of excessive draft called "clear areas" that occupants need to avoid (**Figure 3**). Moreover, hybrid underfloor systems may not provide as dramatic an improvement in air quality at the breathing level as do displacement ventilation systems. Hybrid underfloor systems can handle higher cooling loads than displacement ventilation systems; the cooling load capacity is limited only by the number of diffusers used and the number of clear areas created.

Indoor Air Quality

Underfloor air distribution systems, particularly displacement ventilation systems, provide a natural advantage over conventional overhead systems due to their ability to efficiently move stale and contaminated air out of the occupied space. The pollution level of the air at breathing level is always lower in spaces served by displacement ventilation systems. This phenomenon is a reflection of the "ventilation effectiveness" of the system. Simply stated, ventilation effectiveness indicates how efficiently the system is able to move contaminated air from the room to the return air duct. From an engineering

Figure 3: Hybrid underfloor system airflow

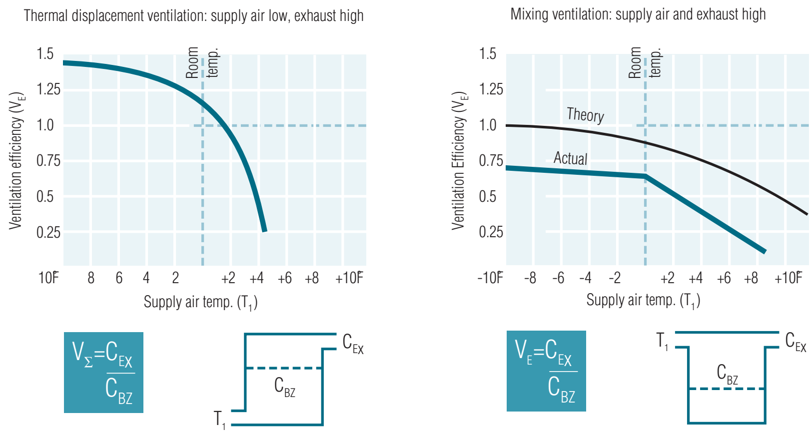
The airflow patterns in a hybrid underfloor system are shown below. The supply diffuser entrains room air, creating a layer of mixed air in the occupied zone. To prevent drafts, occupants should avoid the clear area.



Source: Loudermilk, 1999

Figure 4: Ventilation effectiveness with overhead and displacement ventilation

Ventilation effectiveness as a function of the difference between the supply temperature and the room temperature for overhead and displacement ventilation systems is shown below. Note that the ventilation effectiveness of displacement systems is higher than 100 percent during cooling operation.



Source: Healthy Buildings International

perspective, ventilation or "air-change" effectiveness is defined as the ratio of contaminant concentration in the return air to the contaminant concentration in the breathing zone of the room.

Conventional overhead, fully-mixed systems are designed in hopes of providing exactly 100 percent ventilation effectiveness throughout the room. Since the air in the room is assumed to be perfectly mixed, the concentration of the return air should be the same as that of the room air; hence the ratio of contaminants in the return air to contaminants in the room air is one. Spaces served by overhead systems are prone to common comfort-related problems such as "short-circuiting," "dumping," and "dead spots." Short-circuiting occurs when a portion of the air discharged from the overhead diffuser never reaches the occupied lower space, but instead simply flows directly to the return grille. This can happen in overhead systems if airflow is warmer than room air. Dumping occurs when the velocity of the supply air is too slow to induce mixing and the cold air simply falls, or "dumps," to the floor. This can happen when the air velocity and/or supply air temperatures are lower than the diffuser can handle. Dead spots occur when the location of partitions and furniture relative to the diffuser location inhibit complete mixing in the space creating "dead spots" of air.

In the occupied lower zone of a displacement ventilation system, air is displaced, not mixed, and allowed to stratify. The flow pattern established is called "plug flow," which is very efficient at purging contaminants from the occupied zone. In displacement ventilation systems, ventilation effectiveness around the knees can be as high as 200 percent, while at the breathing level it can be as high as 120-150 percent (**Figure 4**).

The ventilation effectiveness of displacement ventilation systems can approach 150 percent at the breathing level.

Hybrid underfloor systems, by contrast, do not necessarily provide the dramatic increase in ventilation effectiveness that displacement ventilation systems offer, though they are definitely an improvement. They do not produce the plug flow that is so efficient at pushing pollution out of the space. Instead they promote varying amounts of mixing in the occupied space by inducing the recirculation of room air. Mixing in lieu of plug flow intrinsically limits ventilation effectiveness. Hybrid underfloor systems generally provide 100 percent ventilation effectiveness in the cooling mode, the same as a well-designed overhead system. However, the fact that occupants can control the airflow rate to their space improves the perceived quality of air, so overall acceptance of the system is greater than with overhead systems.

Energy Impacts

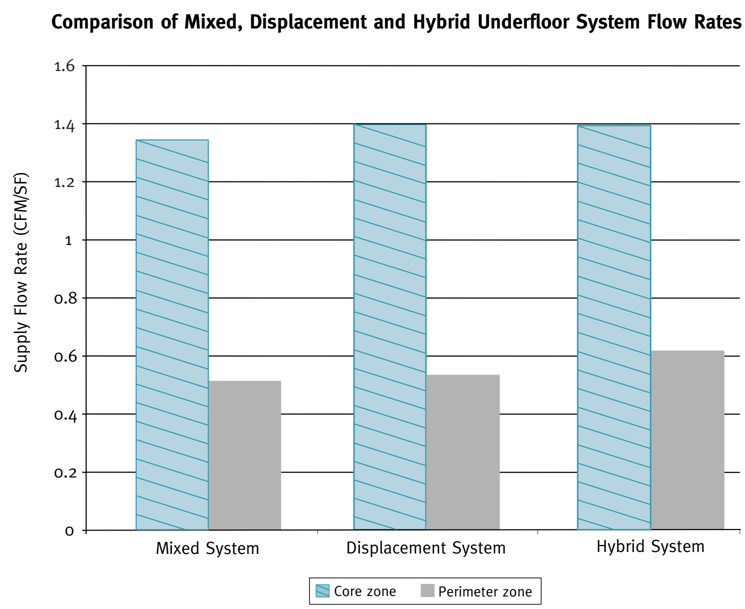
System Design Flow Rate

System flow rates are generally higher in underfloor systems than in conventional overhead systems, since warmer supply air temperatures (65°F vs. 55°F for a conventional system) are used, resulting in a smaller difference between the supply air and the desired room temperature. However, because comfort conditions in an underfloor system are maintained in the lower occupied zone only, the increase in supply air flow rate is less than one might expect. A comparison of design flow rates for a typical office

Underfloor air distribution systems can be very energy-efficient, even at increased flow rates.

Figure 5: Comparison of design flow rate for mixed, displacement, and hybrid underfloor systems

Flow rates for mixed, displacement, and hybrid underfloor systems were calculated for a typical office space. While the flow rates increased for the underfloor systems, the increases were fairly modest.[2]



Source: Architectural Energy Corporation

space is shown in **Figure 5**. The differences in flow rates for each system are fairly modest, on the order of 5 to 20 percent.

Although underfloor systems generally operate at higher flow rates than conventional overhead systems, they typically consume less energy than a conventional overhead system due to a number of factors, including:

1. Reduction in air distribution system pressure drop, reducing the specific fan power, which is the power required to move a given quantity of air (Watts per cfm).
2. Enhanced opportunities for free cooling and evaporative cooling.
3. Higher cooling equipment operating efficiency.

Fan Power

The specific fan power in an underfloor system is almost always lower than in a conventional system since underfloor systems typically require minimal ductwork on the supply side of the system. The cross-sectional area of the underfloor plenum is significantly larger than that of a conventional air duct, thereby reducing air velocity and pressure drop. Horizontal supply ducts are minimized or eliminated as the access floor serves to distribute the air evenly across the floor plate.Terminal boxes may still be required, but diffuser branches can also be eliminated. Typical static pressure design points for underfloor systems are 0.5 to 1.5 inches lower than for conventional systems, resulting in a savings of 12 percent to 38 percent in specific fan power.[3]

Free Cooling

Underfloor systems generally deliver higher-temperature air to the space when compared to overhead systems, so a greater opportunity exists to take advantage of "free cooling" using an air-side economizer. As the setpoint of the supply air temperature increases, warmer outside air can be used to meet the load, so the hours required of the mechanical cooling equipment decrease. Warmer return air temperatures due to stratification also allow an increase in economizer operating hours.

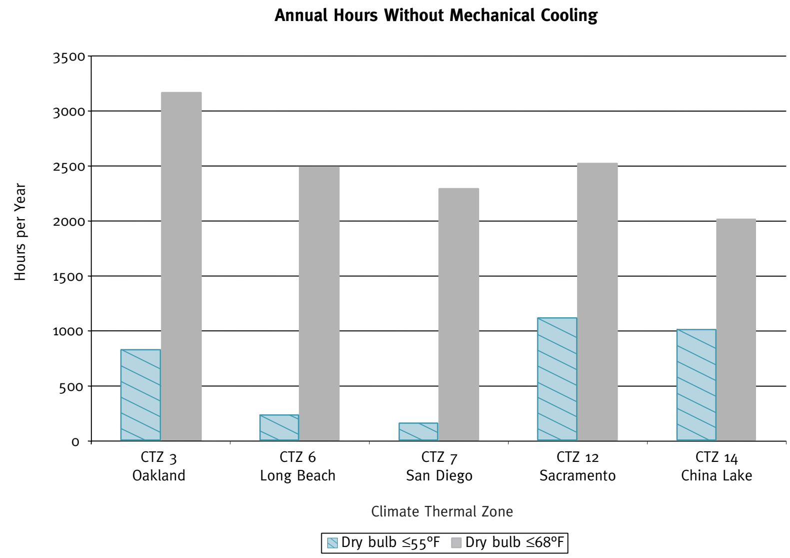
Systems using evaporative coolers can also benefit in the same manner. Just as economizer hours increase in a displacement ventilation system, so do evaporative cooling hours. As the setpoint for the supply air temperature rises, the evaporative cooler can be expected to meet the load over a longer period of the cooling season, without the need for mechanical cooling. The impact of supply air temperature on the number of hours that an economizer system can meet the load without mechanical cooling is shown in **Figure 6,** page 10.

Enhanced Operating Efficiency

Another opportunity for energy savings lies in the increased efficiency of the equipment used to mechanically cool the supply air. Compared to a conventional system, an underfloor system generally delivers warmer air to the space and typically returns

Figure 6: Economizer hours

The figure below shows the number of hours per year that an air-side economizer can cool the building without mechanical cooling in several climate zones in California. By raising the supply temperature from 55°F to 68°F, the number of hours of free cooling increases dramatically.



Source: Architectural Energy Corporation

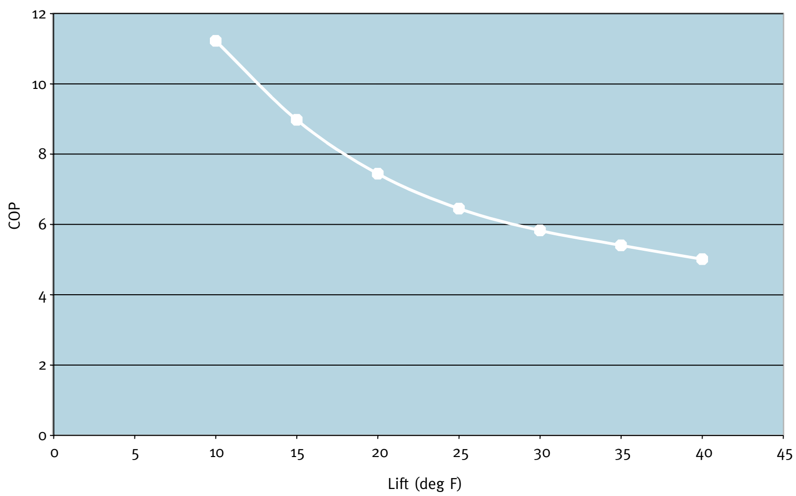
warmer air to the equipment. As the supply air temperature rises, the efficiency of the cooling equipment improves, since there is less "lift" between the supply air and the condensing temperature. The net effect is that the mechanical equipment serving an underfloor air distribution system uses less energy than a comparable conventional system serving the same cooling load. However, one caveat may prevent the designer from fully realizing this opportunity. In spaces with high latent loads, allowing a higher equipment discharge temperature may result in an excessive supply air dewpoint temperature. The air being delivered to the space may not be sufficiently "wrung out" and comfort in the space may be compromised. The designer may mitigate this potential humidity problem without conceding equipment efficiency by using a desiccant dehumidification system.

Access Floor Systems

Access floors are constructed from a series of panels elevated above the original floor by pedestals located at the corner of each panel. The access floor creates an underfloor space through

Figure 7: Coefficient of Performance (COP) as a function of lift

The figure below shows influence of the "lift" on the COP of a centrifugal chiller. Here, the lift is defined as the difference between the leaving chilled water temperature and the entering condenser water temperature.



Source: ASHRAE Standard 90.1999

which power, network, and phone wires can be installed. With a modest expansion in the depth of the underfloor space, a plenum for distributing conditioned air can also be created.

Access Floor Design

Access floor panels are available in four different materials: all-steel; concrete; aluminum; or wood (**Figure 8**). All-steel floor panels have a number of benefits. They are lightweight, which allows for ease of handling; they have a high load performance; and they are noncombustible. Concrete floor panels are used in offices and equipment rooms. They have an excellent rolling load performance and the panels are solid and free from any floor- or plenum-generated noise. They also have excellent grounding and electrical continuity. Aluminum panels, also known as "floating floors," are used in clean rooms and other high-tech locations. These panels are unique in that they are perforated and have grates to provide optimum laminar airflow patterns in a downflow configuration, thus preventing particles from contaminating

Figure 8: Access floor panel

A typical access floor panel is shown in the figure below. The structural panel is supported by adjustable pedestals and covered with a carpet tile.

Source: Tate Access Floors

sensitive machinery and equipment in clean rooms. Floating floors contain no ferrous material to interfere with magnetic fields and are available in a wide selection of conductive, static-dissipative coverings or coatings. Woodcore panels are available as a lower-cost option for offices and equipment rooms. They are durable, quiet, and economical, but building codes do not allow them to be used with underfloor supply systems because they are combustible.

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

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

Wiring Systems

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

A recent advance in cabling technology is the structured cabling system. This system integrates the various cabling needs—data, telephone, power, and building controls—into a set of packaged multifunction cables, complete with junction boxes and snap-in connectors. Data, telecom, standard and isolated ground power is brought to each workstation in a single, multifunction panel. The systems can be extended while under load, maintaining productivity of adjacent workstations during office reconfiguration.

A structured cabling system integrates power, data, telecom, and video into a set of multifunction cables, connectors, and terminal boxes.

HVAC Components

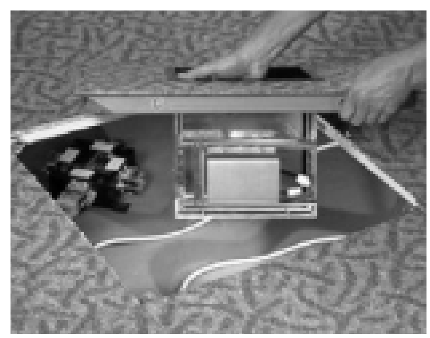
Access floors can also provide the plenum space necessary for installing the air distribution components of an underfloor air distribution system, such as supply air diffusers, terminal units, and optional ductwork. Plenum systems can be either pressurized or operated at neutral pressure. Pressurized plenums generally use passive diffusers; neutral-pressure plenums use fan-powered diffusers. Fan-powered diffusers provide better local control of airflow rate at the expense of additional fan power, noise and cost.

Displacement ventilation systems use diffusers with a sufficient cross-sectional area to limit air velocity to about 40 to 50 fpm. Low-velocity diffusers are available from several manufacturers for use in access floor systems. Airflow rate can be adjusted by the occupants, providing some level of local occupant comfort control. Diffuser location is not particularly critical, since the exit velocity is designed to limit localized draft discomfort.

In hybrid underfloor systems, floor-mounted diffusers are intended to induce room air into the discharge airstream.

Figure 9: HVAC terminals

Two types of HVAC terminals used with access floor systems are pictured below. The top terminal is a thermostatically controlled VAV terminal; the lower terminal is a constant-volume "swirl" diffuser.



Source: Tate Access Floors

A task ambient control workstation allows the occupant to have complete control of the local lighting, HVAC, and ambient sound environment.

Typical diffuser designs include manually adjustable 8-inch-diameter, circular "Swirl-type" models, as well as manually or automatically adjusted, 10 x 10-inch constant-velocity models. The swirl-type models can be installed in 8-inch-high raised floors, while the constant velocity models require 12-inch plenums. Most manufacturers' designs allow occupants to manually regulate the flow through floor-mounted, swirl-type diffusers without removing the diffuser cover. Another style of diffuser allows easy adjustment of flow direction by simply rearranging the supply grilles in one of 16 different orientations. Some floor-mounted devices can be electronically dampered through a locally controlled thermostat.

More elaborate configurations are designed to be mounted directly on the desktop, affording the owner of the workstation arm's-length control of the quantity and direction of flow at head level. These diffusers are typically incorporated in "task-ambient conditioning" (TAC) systems, in which underfloor air is extended through the floor in flexible ducts housed directly in the furniture. The diffuser, akin to that found on an airplane above the passenger's head, is mounted in a desktop console with other environmental control apparatus, such as light and speaker dimmers or switches.

Maintenance and Cleaning

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

Comfort Control and Productivity

Improved comfort can be achieved when the occupants themselves take advantage of the local control features available with an underfloor system. Uncomfortable draft and temperature inconsistencies are two of the most common sources of occupant complaints. With the diffusers at floor level, the occupants can easily redirect or modulate the airflow into their own space and to their own liking, a benefit that is inconceivable with the conventional overhead system. Furthermore, since the diffusers are housed in a modular access floor, it is easier to reposition the diffuser to another location. Comfort is also improved by the reduction in inherent noise levels for pressurized floor systems. Since they operate at lower pressure and velocity, underfloor systems generally produce less noise than traditional overhead systems. However, fan-powered terminals used in neutral-pressure systems may cause a small increase in noise levels.

“We have far fewer temperature complaints, no indoor air quality problems, and much happier occupants,” says Gary Hall, director of facilities at the Gemological Institute of America in Irvine, California.

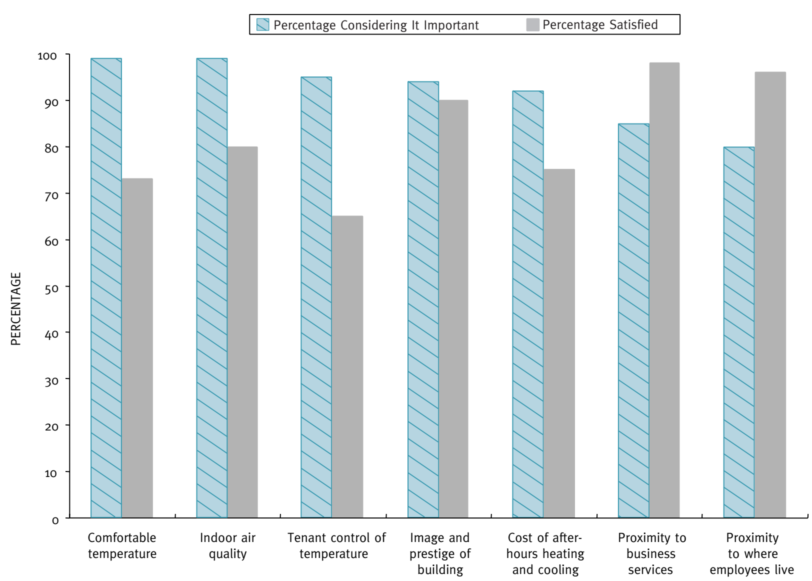
Glenn Shuder, principal architect of the Sacramento Municipal Utility District’s Customer Service Center, says, “The greatest benefit is that our employees have control over their environment and have not placed individual heaters at their desks, due to the vents at the floor and not the ceiling.”

Comfortable employees are productive employees. The connection among air quality, comfort, and productivity is commonly addressed through owner testimonial letters as well as various articles published in trade magazines. Space comfort and air quality are the top occupant complaints fielded by building owners and operators, according to the Building Owners and Managers Association (BOMA). Studies by BOMA point to potential increases in worker productivity of 20 percent by improving indoor air quality. When occupants are satisfied with the temperature and quality of the air in their immediate environment, they spend less time fretting and more time working.

Simply giving occupants control of their personal comfort goes a long way toward meeting this end. The advantages of personal comfort control are documented in a study of the West Bend Mutual Insurance Company's new energy-efficient headquarters (**Figure 10**). The new building has efficient lighting, high-quality windows and shell insulation, and an efficient thermal storage HVAC system. The designers also included unique personal HVAC control features for 430 of the 500 employees. The results of the study estimated an overall increase in worker productivity of 16 percent after the move into the new building. This speaks volumes to the general advantages of energy-efficient design. With respect to the HVAC system in particular, the incremental increase in productivity was roughly 3 percent, which translated to an 18-month payback on the personal control modules. The investigators took this to be an underestimate, since many of the employees reneged on their commitment to the study when they learned they would temporarily lose control over their personal modules.

Figure 10: BOMA occupant satisfaction survey

A survey of building occupants listing their concerns and level of satisfaction. Comfort, indoor air quality, and occupant control of the space temperature are highly ranked issues.[4]



Source: Building Owners and Managers Association

Economics

The basic cost of an access floor system is on the order of $4-7 per square foot. Savings from reduced wiring and HVAC costs during the first tenant improvement bring the net cost down to about $3 per square foot. Access floors inherently reduce ongoing operating costs in spaces with a high churn rate, where people, furniture, and equipment are frequently moved to accommodate changing project or team requirements. Facilities managers can spend less time and money on renovations, since changes in wiring and HVAC services are simple and uncompromising. If cable or HVAC outlets are out of reach or inconveniently located, they are simply moved.

Taken together as an integrated system, the underfloor air distribution system with an access floor can afford the building owner an overall decrease in life-cycle cost. Savings in space remodeling costs over the life of the system can easily pay for the incremental cost. Estimates of savings in ongoing operations, maintenance, and remodeling are shown in **Table 1**.

Table 1: Energy- and non-energy-related cost savings for access floor systems with underfloor air distribution[5]

Category	Estimated Savings
HVAC Energy	15–30%
Operations and facility staff reduction	25–50%
Cost of telecommunications moves, adds, and changes	40–70%
Floor plate modifications cost	40–70%
Power distribution changes to individual workstations	50–80%
Moving computers and peripherals	80–90%
Space unavailable during remodeling	30–70%
Absenteeism	5–10%
Employee disruption and dead time during remodel	50–80%

Source: Journal of the International Facilities Management Association

Like the floor itself, underfloor HVAC components may be depreciated at a faster rate since they are considered equipment rather than part of the building. In the balance, higher

Reconfiguring an access floor system is accomplished by removing the carpet tiles and unbolting the access floor panels, thereby gaining access to the wiring below. Electrical outlets, data connections, and HVAC terminals can be moved to suit the new configuration of the space.

Figure 11: Examples of buildings with underfloor air systems

Underfloor air and access floor systems have been applied to a wide variety of building types and climates, including a corporate headquarters for a major company in California, an electric utility headquarters in Sacramento, and a federal courthouse in Denver (under construction).

Source: GAP Inc./SMUD/Anderson Mason Dale Architects

installation costs associated with the access floor can be offset by lower first costs in wiring and HVAC system costs, lower operations and maintenance costs, and higher occupant satisfaction. Finally, with flexibility and accessibility come the advantages of adaptability. Buildings served by raised floor systems have the advantage of deferred obsolescence. As they are more adaptable to changes in wire and HVAC service requirements, they can maintain market value over a longer period of time.

Applications

Certainly any spaces that are designed with the "open office plan" are good candidates for underfloor air. Whenever high employee churn rate is an inherent characteristic of the space, the underfloor system is a natural choice. As occupant loads are frequently added, subtracted, shuffled, and moved, the flexibility and accessibility of the underfloor system serve as a great financial benefit to the building owners and operators, saving time and money with each renovation.

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

Examples of high ceiling spaces where underfloor supply and displacement ventilation systems may be successfully implemented are theaters, courtrooms, lobbies, and industrial and manufacturing facilities. Spaces with low sensible loads in the occupied zone also provide good opportunities for designers of underfloor systems because they inherently require less airflow and therefore pose less risk of a draft.

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

Other good candidates for underfloor air systems are industrial and manufacturing facilities where heat-producing processes like soldering, brazing, welding, grinding, and machining can be served very effectively by a displacement system. In Scandinavia, displacement ventilation systems account for upwards of 50 percent of industrial market share.

Applications that may not work well with displacement ventilation are those in which the pollutant sources are heavier than air and not accompanied by heat. Some chemical and biological manufacturing or laboratory spaces, for example, may not lend themselves to successful implementation of displacement ventilation systems.

Design Considerations

Temperature Gradient

In order to maintain occupant comfort, underfloor air systems must limit the temperature gradient in the occupied space. In order to limit the gradient, supply air temperatures on the order of 65°F to 68°F are used with a recommended minimum ceiling height of 8 feet. The supply air must be introduced to the occupied lower space at a high enough flow rate to prevent an uncomfortable temperature gradient between head and foot, but at a low enough velocity to prevent the sensation of draft and prevent mixing in the upper stratified zone. A temperature gradient between head and foot that is greater than 5°F is considered excessive. A gradient of 3.5°F is considered to be a good design criterion, not too large by most people's standards.

The trade off between system flow rate and temperature gradient is one of the most important decisions facing the designer of an underfloor air distribution system.

Airflow Rate

The airflow rate must be balanced against temperature gradient considerations. Lower temperature gradients imply higher flow rates and excessive fan energy. If the air volume is too high, occupants are more likely to be exposed to drafty conditions resulting from high-velocity currents discharging into the occupied lower portion of space. Conversely, if the air volume is too low, the occupants are more likely to be exposed to uncomfortable temperature gradients between their ankles and head. The high load problem may be mitigated in applications where sufficient floor area is available to supply high volume through more or larger diffusers, effectively reducing the localized air velocities while maintaining a high limit on temperature gradient. Installing diffusers that give the occupant the benefit of local control may also mitigate the high load problem, as they allow immediate adjustment of both velocity and direction of flow.

Combined Underfloor and Conventional Systems

Designers of buildings with both underfloor and overhead air distribution systems should consider using separate air handling and mechanical cooling systems dedicated to each air distribution system type, to avoid compromises that reduce the energy efficiency of the underfloor system.

Designers need to be cautious in buildings where the plan calls for the parallel installation of displacement and overhead systems. Technically it would be a fairly simple matter to design this hybrid underfloor system with a common plant and air handler. However, because the energy-saving features of the displacement system hinge on the production of higher-temperature supply air, many energy savings opportunities are lost when combining underfloor and overhead systems on the same air-handling system or plant.

When combining air-handling systems, the supply air temperature is set according to the needs of the overhead system. For spaces served by underfloor systems, some type of zone level mixing is generally provided (e.g., fan-powered mixing boxes) to warm up the supply air before it can be supplied to the space, since it would be too cold for direct injection. Fan-powered mixing boxes increase first costs and fan energy and reduce the effectiveness of the air-side economizer. Another problem with combining air handlers is the difference in pressure required. Conventional VAV systems require significantly higher supply pressures than underfloor systems. Combining them requires a throttling device to reduce the pressure before supplying air to the underfloor plenum, which wastes fan energy. To avoid this compromise, the designer should consider separate air-handling systems for each type of distribution system.

Serving both conventional overhead and underfloor systems with the same chiller plant can be both problematic and inefficient. Since the overhead system supplies colder air, the overhead air handlers will require that the cooling plant operate in mild weather when the underfloor air handlers do not need cooling. This will increase the number of hours the plant operates, and it may cause the plant to operate inefficiently if loads are very low (e.g. if the conventional air handler load is small relative to the total plant load). Chilled water supply temperatures will also have to be lower for the overhead systems due to their low supply air temperatures, reducing plant efficiency under all load conditions.

Plenum Conditions and IAQ

While underfloor systems are generally advertised as offering an improvement in indoor air quality, consideration must be given to the possible effects of condensation buildup in the plenum. Condensation can be a concern in underfloor systems if the cool plenum is suddenly exposed to warm, moist air. The dewpoint of the air entering the plenum must always be greater than the lowest temperature of any exposed surface within the plenum, otherwise condensation will occur. This phenomenon can be avoided if the plenum is well sealed against outside air infiltration, and if sudden step-changes in supply air conditions are avoided. For example, when the fan shuts down at the end of the day, warm and moist air should be

Care must be taken in the design of HVAC control sequences to avoid unintentional moisture condensation in the underfloor space.

blocked from rushing into the cool plenum. Similarly, during occupied hours, if the mechanical cooling abruptly shuts down and the dewpoint of the supply air suddenly rises, the fan may need to be shut off, or the outside air dampers adjusted. Condensation concerns need particular attention when the slab thermal reservoir is used to cool the space. For example, after the slab is "charged" with cool air at night, the mechanical system must be controlled to ensure that it does not supply air that exceeds the temperature of the coolest surface in the plenum. This can be a problem with systems installed over a slab on grade, since the slab temperature will be difficult to control, and condensation can occur.

Some questions may also arise regarding the inherent quality of the air that passes through an underfloor plenum prior to discharging into the space. Off-gassing from cabling, cement dust shed from the slab, debris and spills sifted down through the floor, and biological growth due to moisture are all possible sources of pollution that could degrade the quality of the ventilation air before it even enters the space. Allowances for these ill effects need to be considered during design of the system. Floor panels can be manufactured and installed to close tolerances, diffusers can have traps that capture spills and debris and can be easily cleaned, and slabs can be sealed to reduce dust and inhibit bacterial growth.

Impacts on Building Design

Floor-to-floor heights need not increase when using an access floor system.

In most applications, floor-to-floor heights are not impacted, because the depth of the ceiling plenum can be reduced when an access floor system with underfloor air distribution is used. Locations of return air grilles are not critical so long as they are located near the ceiling level. With careful consideration of return air system and lighting design, it may be possible to reduce floor-to-floor heights while maintaining the same floor to ceiling dimension. This is particularly true for buildings that do not have hung ceilings, a design that is made practical by the elimination of overhead ductwork and wiring that the ceiling was intended to conceal. Local fire codes may place conditions on running wire in an HVAC plenum. Fire-rated wiring and/or conduit will be required in almost all jurisdictions. The plenum size may also be limited by the fire code, so it may be necessary to partition the plenum into smaller subspaces. It may also be necessary to install smoke detectors in the plenum.

Perimeter Systems

Perimeter systems are required to respond to time-varying heat gains and losses through the building shell. While occupant control of relatively constant interior loads is reasonable, manual control for the ever-changing perimeter loads is not, and therefore underfloor plenums may need to be zoned based on building exposure, especially when using passive diffusers. The plenums can be partitioned and fed with separate supply air ducts as needed. In hybrid underfloor systems, fan-powered VAV terminal boxes can provide extra cooling to the building perimeter. These boxes can be supplied with integral heating coils to provide perimeter heating as well. Displacement ventilation systems do not function well in the heating mode. Generally, separate perimeter radiation is provided to meet envelope heating loads.

Design Methods

Underfloor air distribution systems involve a considerably different process than with overhead systems when calculating space load, supply flow rate, and temperature, along with selecting the size and number of diffusers. A variety of methods are available for finding the optimal design values, some more complex than others. The type of underfloor system being installed, displacement ventilation or hybrid, plays a role in choosing the design methodology. The most complex and rigorous design methods usually involve use of computerized computational fluid dynamics (CFD) analysis, which is generally reserved for research applications or very large projects with unique conditions. Simplified design methods have been developed to assist the designer with more mainstream design problems.

Displacement Ventilation Design

A simplified method for displacement ventilation design has been developed by ASHRAE, which is based on CFD analysis but does not require CFD in its implementation.[6] The method uses empirical formulas derived from CFD models of prototypical office and classroom spaces, and predicts occupied zone cooling load, temperature gradient, and system flow rate from the occupied zone heat sources (occupants, equipment, and desk lamps), overhead lighting, and exterior loads (envelope conductance and solar gains). Empirically derived weighting factors are used to estimate the occupied zone load from these components of the total space load. System flow rate is calculated assuming a maximum temperature gradient of 3.5°F in the occupied zone. Empirical formulas are also provided to calculate the ventilation effectiveness and other IAQ parameters.

Hybrid Underfloor System Design

A simplified design method has also been developed for hybrid underfloor systems, called the Effective Sensible Heat Gain (ESHG) method.[7] In a manner similar to the displacement ventilation design method, the sensible load between the head and foot region is estimated by applying weighting factors to the components of the total zone load. System flow rate is calculated from the occupied zone load and the maximum allowable differential in the supply air and occupied zone temperatures. The weighting factors used in the ESHG method are based on engineering judgment. Research being conducted at the Center for the Built Environment at UC Berkeley will result in a more rigorous design method for these systems.

For More Information

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)

ASHRAE is organized for the sole purpose of advancing heating, ventilation, air conditioning, and refrigeration for the public's benefit through research, standards writing, continuing education, and publications.
1791 Tullie Circle, NE
Atlanta, GA 30329
Phone: (404) 636-8400
Fax: (404) 321-5478
www.ashrae.org

1997 ASHRAE Fundamentals Handbook, pg. 31.5–31.8. 1997.

"A Critical Review of Displacement Ventilation." Xiaoxiong Yuan, Qingyan Chen, and Leon R. Glicksman. Vol. 104, Pt. 1. 1998

"Assessment of the Performance of Ventilated Floor Thermal Storage Systems." Michael J. Holmes and Alexandra Wilson. 1996.

"Comparison of Heating and Cooling Energy Consumption by HVAC System with Mixing and Displacement Air Distribution for a Restaurant Dining Area in Different Climates." Alexander M. Zhivov and Adolf A. Rymkevich. Vol. 104, Pt. 2. 1998

"Development and Application of an Underfloor Air-Conditioning System with Improved Outlets for a 'Smart' Building in Tokyo." Katashi Matsunawa, Hiroshi Iizuka, and Shin-ichi Tanabe. 1995.

"Experimental Study on the Floor-Supply Displacement Ventilation System." Takashi Akimoto, Tatsuo Nobe, and Yoshihisa Takebayashi. 1995.

"Integrated Access Floor HVAC: Lessons Learned." R.W. Shute. 1995.

"Measurements and Computations of Room Airflow with Displacement Ventilation." Xiaoxiong Yuan, Qingyan Chen, Leon R. Glicksman, Yongqing Hu, and Xudong Yang. Vol. 105, Pt. 1. 1999.

"Underfloor Air Distribution Solutions for Open Office Applications." Kenneth J. Loudermilk. Vol. 105, Pt. 1. 1999.

"Underfloor Air Distribution Systems: Benefits and When to Use the System in Building Design." Blair T. McCarry. 1995.

Engineered Systems.
"Issues & Events." September 1999.

HPAC Engineering.
"Design for Commercial, Industrial, and Institutional Facilities." William A. Turner. October 1999.

Journal of the International Facilities Management Association.
"Access Floor—Don't Plan Your Building Without It." Theodore R. York. Nov./Dec. 1992.

University of California at Berkeley
390 Wurster Hall
Berkeley, CA 94720
Phone: (510) 642-4950
Fax: (510) 643-5571
www.cbe.berkeley.edu

Center for the Built Environment. "How Low Can You Go: Air Flow Performance of Low-Height Underfloor Plenums." Fred Bauman and Paolo Pecora. October 1999.

Center for the Built Environment. "Giving Occupants What They Want: Guidelines for Implementing Personal Environmental Control in Your Building." Fred Bauman. October 1999.

Center for Environmental Design Research. "Task/Ambient Conditioning Systems: Engineering and Application Guidelines." Fred S. Bauman and Edward A. Arens. October 1996.

Notes

1 Maximum cooling load depends strongly on room height, ventilation rate, and heat source type and location. Maximum practical loads are limited by fan energy and diffuser outlet surface area. See "Performance Evaluation and Design Guideline for Displacement Ventilation." Xiaoxiong Yuan, Qingyan Chen, and Leon Glicksman. ASHRAE Transactions, Vol. 105, Part 1. 1999.

2 Calculations are based on design methods presented by Yuan et al, 1999, and Loudermilk, 1999 (see For More Information). Overhead lighting loads set at 1.5 W/SF; plug loads set at 1.0 W/SF. Peak cooling load for the core space is 11 Btu/hr-SF; peak load for the perimeter space is 29 Btu/hr-SF.

3 Based on a design pressure drop of 4 inches WC for a conventional system.

4 "What Office Tenants Want: 1999 BOMA/ULI Office Tenant Survey Report." BOMA International Foundation: New York (2000).

5 York, Theodore R. "Access Floor—Don't Plan Your Building Without It." Journal of the International Facilities Management Association, Nov./Dec. 1992.

6 For more information see, "Performance Evaluation and Design Guidelines for Displacement Ventilation," by Xiaoxiong Yuan, Qingyan Chen, and Leon Glicksman. ASHRAE Transactions, Vol. 105, Part 1, 1999.

7 For more information see, "Underfloor Air Distribution Solutions for Open Office Applications," by Kenneth J. Loudermilk. ASHRAE Transactions, Vol. 105, Part 1, 1999.

Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our Web site at www.energydesignresources.com.

This design brief was prepared for Energy Design Resources by Architectural Energy Corporation, Boulder, CO.