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Underfloor Air Distribution: Lessons Learned

By Allan Daly, P.E., Member ASHRAE

HVAC systems using underfloor air distribution (UFAD) promise multiple benefits. These include:[1] improving occupant satisfaction by providing control over personal air supply through use of manually adjustable diffusers; making building systems more flexible and easily re-configurable, with the effect that "churn"* can be less expensive; improving room ventilation by delivering fresh air closer to occupants; and reducing building energy use due to decreased central fan energy, extended economizer cooling, and improved cooling-cycle efficiency.

These benefits come with a price. The initial cost of construction using UFAD systems is typically higher than in comparable overhead systems. In recent projects, there has been a \$3 to \$5 per ft^2 (\$33 to \$55 per m^2) premium depending on specific building design, including the cost of the access floor. The challenge to a team designing a building with UFAD is to capture as many of the benefits as possible while keeping the initial cost increase to a minimum.

With that goal in mind, here are three design and construction topics to consider when using UFAD. These topics come from experiences on seven recent projects, and reflect feedback from owners, designers, contractors, occupants, and building operators.

Minimize Ductwork in the Plenum

A major benefit of UFAD is system flexibility. The raised-floor plenum provides a convenient and accessible route for all building services from the building core out to the point of use. Services include air distribution, of course, but also can include heating-hot-water piping for perimeter systems, electrical and telephone/data cabling (typically run in cable trays), sprinkler mains, domestic water piping, and drains.

In the best case, these services share the plenum with a "loose fit" that provides room for each to be modified easily. In the worst case, these co-existing and co-located services make coordination a complex and difficult task. Where conflicts occur, ductwork or "air-highways"** are typically involved because they take up more room than any of the other services. Detailing air-distribution crossovers invariably ends up with notched or penetrated ducts, making for a difficult or inefficient installation.

Furthermore, while cable can be pulled through the plenum easily, and there is usually enough room to work on piping, hard ductwork or plenum dividers are much more difficult to reconfigure and doing so requires access to large areas of the plenum.

The lesson: avoid ductwork and air highways in the plenum, wherever possible.

A better design strategy is to use multiple vertical shafts serving a single plenum. This can result in significant flexibility gains, and can reduce the overall first cost of a project. Consider the following case study.

Multiple Shafts in an Office Building

The project is a 100,000 ft^2 (9290 m^2) office building located in northern California. The building is three stories tall with approximately 35,000 ft^2 (3252 m^2) floor plates. This "green" building's floor plate is arranged in a V-shape, which gives

*"Churn" refers to the annual percentage of workers and their associated workspaces that are reconfigured or undergo significant changes. It reflects the frequency at which companies relocate, upgrade, and expand offices, furniture, and equipment. A recent International Facilities Management Association (IFMA) survey found an average churn rate of 44% for U.S. office buildings. For more information, see *Understanding the Dynamics of Churn* by Jon Ryberg at www.facilitiesnet.com/fn/NS/NS3chrn1.html.

**"Air highway" refers to the use of sheet metal walls within the raised floor plenum to accomplish horizontal air distribution. The dividers create higher-pressure zones within the plenum that allow air to be routed similar to ductwork. The air highways use the raised-floor itself as the top and the slab as the bottom of the enclosure; sheet metal is used on the sides.

About the Author

Allan Daly, P.E., is a principal at Taylor Engineering, Alameda, Calif.

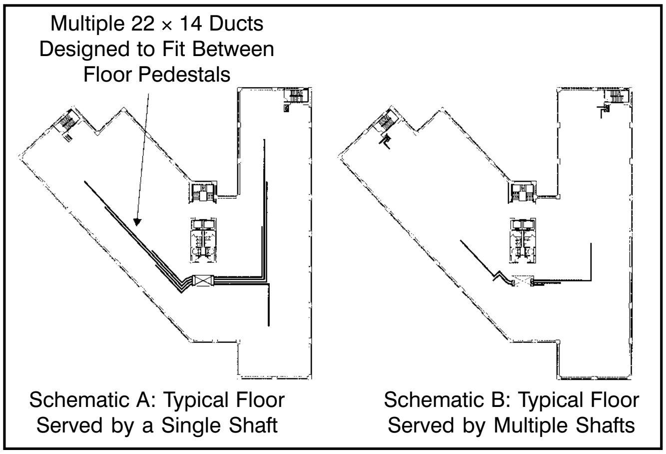

Figure 1: Single and multiple shaft schematics.

Figure 2: Gap where a structural wall extends to the slab.

the building an extended perimeter and holds the width of the building to 90 ft (27 m) maximum. This geometry allows daylight to be used across the building and makes cross ventilation possible via operable windows. Build-out and furnishings are planned to be mostly open-office with cubicles.

Given the symmetric V-shape, the initial HVAC design strategy was to use a single central shaft with a built-up air handler on the roof. This has proven to be an efficient design for conventional systems and seemed appropriate here. Horizontal ducts distribute air through the floor plenum. Ducts are provided with a length adequate to limit air travel in the open plenum to 50 ft (15 m). Schematic A in *Figure 1* shows a typical floor plate and illustrates the shaft and horizontal ducts. Multiple 22 × 14 standard ducts are arranged to fit between the pedestals of the raised floor system.

As other services are laid out around and across the ducts, coordination becomes difficult. For example, data services need to cross at many points, typically requiring ducts to be notched. Electrical boxes and air outlets need to be placed to avoid the ducts, which restricts the layout of cubicles.

An alternative multiple-shaft design was developed to address the coordination issues (Schematic B of *Figure 1*). In this scheme, an auxiliary supply-duct shaft located at the end of each wing augments the central shaft. Supply ducts running across the roof supply the two new shafts.

Coordination is significantly eased as is evident in the schematic. Savings from the reduced horizontal ductwork were offset by increased shaft and fire/smoke damper requirements, but the change reduced overall project cost by $250,000.

One disadvantage to this approach is less architectural flexibility because the shafts are immovable elements that need to persist through any remodels. In this case, this issue was mitigated by associating the shaft with the stairs at the ends of the building, which are also permanent features.

Prevent Plenum Leakage

As a key element of good building design, system integration has inherent benefits—when one building element serves multiple functions, a cost- and resource-efficient design results. With UFAD, the raised access floor provides air distribution, conceals and protects cabling and other services, and provides a stable and level walking surface. However, integration involves multiple performance demands for a given building element, as well as overlapping roles and responsibilities for the design and construction team.

One pitfall of integration in this case is air leakage. In UFAD systems, a substantial portion of the air distribution system in a building is furnished and installed outside of Division 15, and this dilutes the ability of the mechanical engineer to control the quality of air pathways.

Consider the following example: At a raised-floor installation in a warehouse retrofit, seismic braces were added to strengthen an existing tilt-up building. The seismic braces extended to the structural slab to provide shear transfer. The access floor had to be installed around them. The floor installers neatly trimmed and fit the tiles, but the general contractor, not understanding the leakage issues, did not seal the stud walls containing the braces at floor level. Had the wall finishes been installed, there would have been large unsealed openings into the floor plenum allowing supply air to short-circuit directly into the return plenum. *Figure 2* shows a typical wall before the contractor installed plugs at the floor level.

Mechanical engineers need to work closely with architects to ensure that edge details all around the floor plenum are well sealed. Details of window-wall connections to the slab and at stair landings and shaft walls require sealed joints. The type of detailing required is analogous to pressurized stairwell and smoke-barrier construction in high-rise buildings.

Detailing alone is not enough. In a recent project, an architectural detail showed caulk sealing around the plenum. During a site visit, the engineer noticed that the caulk was not installed. Contractors are not used to this level of treatment throughout a building, so designers need to inform them of the sealing requirements and work with architects during con-

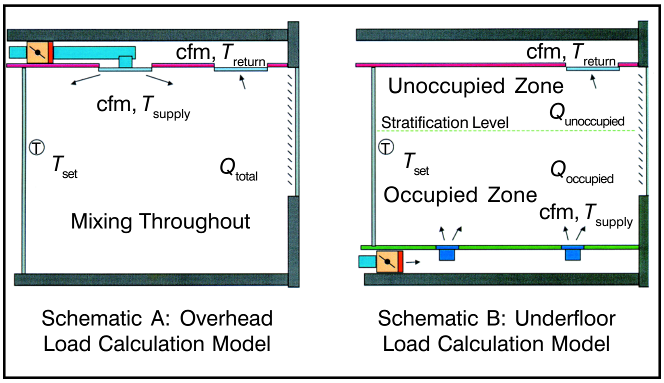

Figure 3: Load calculation models.

struction administration to verify proper installation.

In designs that use the "air highway" approach to horizontal distribution, leakage from these can be significant because of the higher pressures. At one installation with air-highways, the joints in the access floor had to be sealed with caulk and the carpet tiles glued-down with adhesive to prevent the carpet tiles from "floating" due to air leakage. Furthermore, air highways often are repeatedly penetrated as other building services cross them. These sheet metal dividers in the plenum are easy to modify in the field and penetrations often are left unsealed.

Allow Airflows to Vary Everywhere

A symptom common to completed UFAD projects is that measured return air temperatures are not as high as manufacturer's data suggests they should be. Addressing this problem requires an understanding of how airflow and loads in a UFAD system differ from a conventional overhead system.

In an overhead system, the basic airflow calculations are straightforward for a single zone at steady state, as shown in *Figure 3*, Schematic A. Air moves through the room at a flow rate (cfm). The supply temperature (T_{supply}) is fixed at the system level, and the load in the room (Q_{total}) is a sum of the heat gains in a space. Assuming the diffuser is designed to fully mix the air in the room, the zone setpoint temperature (T_{set}) equals the return air temperature (T_{return}). These quantities are related by the formula below expressing the room energy balance.

$$Q_{total} = \left(1.1\frac{\text{Btu}}{\text{hr}\cdot\text{cfm}\cdot{}^\circ\text{F}}\right)\times \text{cfm}\times\left(T_{return} - T_{supply}\right)$$

The airflow calculation for an underfloor system needs to be broken into two parts instead of one because of two distinct room regions that develop. For simplicity, assume that both regions are fully mixed but separated by a "stratification layer" defined as a point in the path of air above which the air never returns to the lower occupied zone. (See related article on Page 28, which discusses the way air stratifies in UFAD systems.) A separate energy balance equation can then be written for each of the distinct zones. For the occupied zone, the equation is:

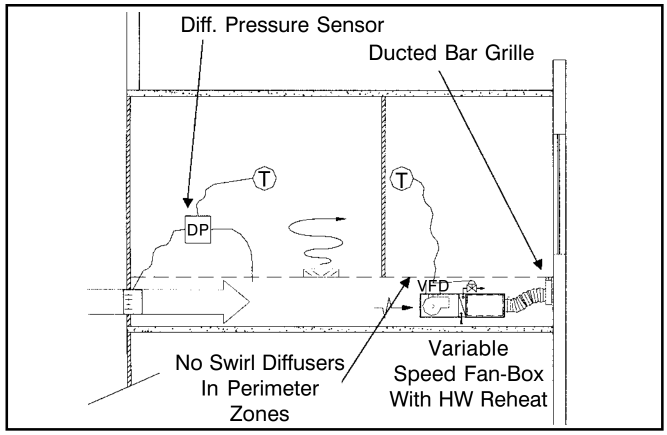

Figure 4: Cascading control loop to make a variable-volume interior zone with an independent perimeter system.

$$Q_{occupied} = \left(1.1\frac{\text{Btu}}{\text{hr}\cdot\text{cfm}\cdot{}^\circ\text{F}}\right)\times \text{cfm}\times\left(T_{set} - T_{supply}\right)$$

A second, similar equation describes the unoccupied zone.

$$Q_{unoccupied} = \left(1.1\frac{\text{Btu}}{\text{hr}\cdot\text{cfm}\cdot{}^\circ\text{F}}\right)\times \text{cfm}\times\left(T_{return} - T_{set}\right)$$

The key to using these equations properly is correctly assigning the load in a room to the occupied and unoccupied zones in the room as follows.

$$Q_{total} = Q_{occupied} + Q_{unoccupied}$$

Unfortunately, no validated methods exist to guide engineers assigning loads (e.g., solar, lights, equipment, and people) to the occupied and unoccupied zones, so currently those decisions are left to the engineer's judgment.

If an engineer is conservative and assigns too much of the load to the occupied zone, more air than needed is supplied to the space. In a variable air volume zone, the air quantities can throttle back in response to the zone controller and bring the space under control. In a constant air volume zone (many interior UFAD zones are designed as such for simplicity), too much air causes space and return air temperatures to decrease.

Field experience suggests that "over-airing" is a common problem in constant-volume zones. For example, in one recent post-occupancy project site visit, every diffuser in the open office cubicles had been manually closed. Inquiries revealed many "too cold" complaints. These symptoms are consistent with providing too much air to the space.

Another factor to consider is the combined cooling effect created by air leakage through the raised floor coupled with the radiant and convective cooling effect of the large, cool floor surface. Testing by one manufacturer places the effect of this non-diffuser cooling at the equivalent of 0.15 to 0.25 cfm per ft^2 (0.762 to 1.27 L/s per m^2) at 0.05 in. w.c. (12.4 Pa), depending on the type of carpet used.[2] For an interior zone with efficient lighting and equipment, this effect can account for up to 50% of the required cooling. Unless this effect is considered when assigning airflows to interior zones, more overcooling may result.

Variable air volume control in interior zones is one way to minimize overcooling and low return air temperatures. An example of a system design that provides large variable volume interior zones is shown in *Figure 4*. The system consists of a cascading control loop where the temperature sensor resets the plenum differential pressure setpoint. The underfloor supply damper then modulates to maintain the plenum differential pressure at setpoint. The perimeter units are not affected by interior zone plenum pressure because they are fan powered and selected with zero inlet pressure for their design conditions.

Conclusion

This article contains practical design advice for buildings with UFAD systems. By providing feedback on lessons learned from experience on specific projects, the author hopes to contribute toward improving the way UFAD systems are designed and installed, and encourage similar knowledge sharing by others.

References

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2. Reese, J.A. York International Corporation, vice president Air Products Group. Personal Communication, February 2002.