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Integrating access floor plenums for HVAC air distribution

Knowledge gained from a Toronto prototype project may encourage engineers to use this new technology in other office buildings

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In recent years, we have witnessed rapid developments in office automation. However, the design of HVAC services for the automated office environment has not kept pace with these advances. This situation forces traditional HVAC systems to be compromised in their ability to meet present and future needs.

It is time to create solutions that are complementary to the demands of the electronic office environment. At a minimum, these solutions should provide:

- True flexibility within the HVAC system for expansion and alteration, preferably to be achieved with plug-in ease;
- Compatibility with access floors, systems furniture and a wide variety of load conditions;
- Minimal first-cost, but not at the sacrifice of economy of alteration (a cost to be repeated frequently throughout the life of the HVAC system);
- Individual, economical user control, where desired;
- Reduced operating costs; and
- Improved air quality.

The access floor has become an intrinsic element in today's electronic office environment. How can one economically and effectively integrate mechanical services into this facility that was originally devised for cable management? Some answers were recently provided by an integrated access floor HVAC system that was installed in an office building in Toronto.

The evolving solution

The common element that limited mechanical distribution flexibility was the insistence of the engineering fraternity to duct conditioned air directly to the space. However, several successful underfloor supply methods were observed, with convincing evidence that the floor-level supply of conditioned air was practical.

For example, engineers in South Africa developed methods for mass thermal storage and distribution of ventilation air unducted. Together, these concepts formed the genesis of several new system configurations, which were put to paper tests and, ultimately, to laboratory tests.

Throughout this development and subsequent periods of prototype observation, a series of system variations were designed with the following common elements:

- Concrete-filled steel or precast concrete access floor panels raised 14 in. (350 mm) to 18 in. (450 mm) above the structural slab.
- Cool air supplied at neutral pressure through a limited amount of ductwork to enhance underfloor mixing of primary air with recirculated air (return air from th space).
- A perimeter fan coil or increment water-source heat pump system installe within the access floor and sized to neutra ize building envelope heat gains and losse
- Individual user fan-driven supp air terminals, mounted under an acce floor panel or within the access floor pl num space and ducted to floor termina

In practice, the integrated access flo HVAC system facilitated future revisio because the air distribution is not har connected to the user terminals. Loc workstation air-conditioning contr devices (or air terminals) that transfer su ply air from the floor plenum to the spa may be relocated in less than five minut using only a screwdriver.

Because the access floor plen serves as a common cool air reserv capacity to any zone may be adjusted adding or removing an air terminal. ductwork revision is required to alter c trol zones or capacities.

The net effect is a system of remar ble flexibility that may be modif quickly, at a fraction of the cost of con tional systems and without the nee employ and coordinate skilled tradesn

The ductwork that is installe intended to remain as-is through all fu modifications. Only a security wa major demising wall or a special area as a computer room should cause or consider revising the underfloor ductw

This configuration resulted i integration of services within the a floor, hence the name integrated a floor HVAC system.

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About the author

Robert W. Shute is the president of The Mitchell Partnership Ltd., Toronto, Canada. He received his B.A.Sc. in mechanical engineering at the University of Toronto. Shute is a past-chairman of the ASHRAE Region 2 R&T Committee and is a member of the Association of Professional Engineers of Ontario and the Association of Professional Engineers, Geologists and Geophysicists of Alberta. He lead the design evolution of the system described in this article in a four-phase project in Toronto.

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The access floor plenum (the mass of the structural floor plus the access floor) must be subcooled before each day's operation to allow cool air to migrate throughout it without significant changes in air temperature. Typically, this means a system startup at about 4:00 am.

Mass thermal storage

The physical relationship of cool conditioned air to the mass of the structure and the access floor facilitates thermal storage by a strategy that uses a temperature swing of the mass through a daily cycle.

During a winter night, the mass may be subcooled in the process of after-hours heating to provide low-grade heat for night setback space heating. Simultaneously, a cool reservoir is created to assist in the next day's occupied cooling load (heat gain).

During the day, this heat gain becomes stored and is recovered as waste heat to assist in the following night's heating.

During the summer, off-hour subcooling of the structural mass helps defer electrical peak demand charges the following day.

In the spring or fall, cooler nighttime air may be used to subcool the mass, reducing the amount of mechanical refrigeration required for the following day.

Design calculations

In design, conventional load calculation practices are utilized, except for determining the mass thermal storage load modification.

At the prototype project (which to date has provided experience with four system variations), site observations have indicated that the 24-hour-cycle active mass thermal storage potential is available from at least the mass of the access floor plus a portion of the structural slab equivalent to 2.5 in. (65 mm) of concrete.

This building mass experiences a temperature swing of approximately 80% of the range of plenum air temperatures imposed during charging and discharging cycles. Therefore, each project must be individually assessed for its mass thermal storage charactertics.

System configurations

For central supply air systems, the discharge pressure in the supply shaft is quite low, controlled at 0.8 in. wg (200 Pa) or less. This pressure is broken at VAV dampers at the shaft takeoffs into the floor plenum at each level.

For compartmental (local) air distribution, the discharge pressure is likely to be 0.25 in. wg (62 Pa), having only fan modulation for overall VAV control of the total area served by that unit. Each unit would serve an area not greater than 10,000 ft^2 (930 m^2).

The floor plenum is virtually at a neutral pressure, nominally 0.02 in. (5 Pa) negative, to the space. Influenced by the operation of perimeter system air movers and air terminals, the air exchange rate will be higher from the floor plenum to the occupied space than it is from the source of conditioned supply air.

This will force a blending of space air with the floor plenum air, increasing the floor plenum temperature above that of the supply air temperature. In most environments, it must be blended above 63 °F (17 °C) to prevent condensation on the structure and to reduce the coldness of the supply air.

Primary supply air ductwork from shafts or compartment units feeds a series of air nozzles that mix supply air with space air. This mixed air is then induced down column furring spaces or induction shafts nominally at centers not greater than 30 ft (9 m).

Proper mixing of supply and return air is the key aspect to successful operation. *Figure 1* depicts a typical layout.

For central systems, velocity sensors are located in both the supply and return ducts to allow control of a fixed differential between supply and return air quantities, as with any VAV system. The nearly neutral pressure differential between the floor plenum and space is controlled a temperature sensor located in an i tion (space transfer to floor plenum) (see *Figure 2*).

As long as a normal space tem ture is sensed, it is evident that spac being drawn into the floor plenum control resets the air volume to ma the average space temperature.

If the temperature in the indu shaft drops dramatically, it indicate the floor plenum is overpressured. results in a reversal of the normal direction. The controls then cause th ply air to be throttled, as that tempe sensor serves the VAV temperature c function as well and it only knows th sensed temperature has fallen. Thi vides a rapid response to a reducti space load.

For compartment systems, the partment unit volume is determine strategically located temperature that also indicates flow (as above). It tains approximately 0.02 in. wg (5 Pa tive pressure in the access floor plen adjusting the supply air volume to the overall space load.

For both central and compartm ized air handling, there are so many ings between the space and floor p that great pressure differentials cou be established. Thus, in both cases, rection of flow indicates the presen positive or negative pressure, whi pressure is actually below a rang could be sensed.

The supply air provides the p source of cooling. The previously de

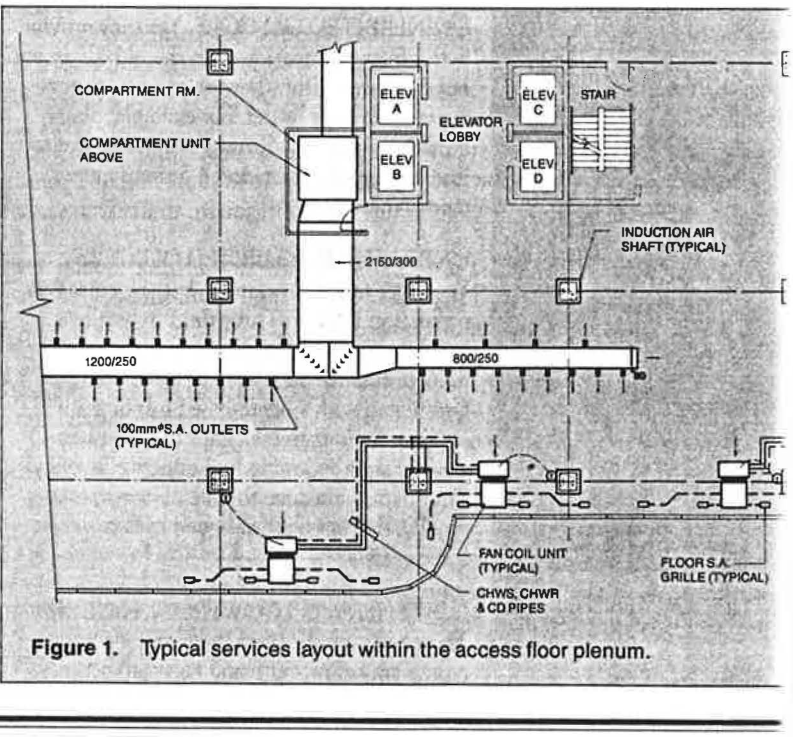

Figure 1. Typical services layout within the access floor plenum.

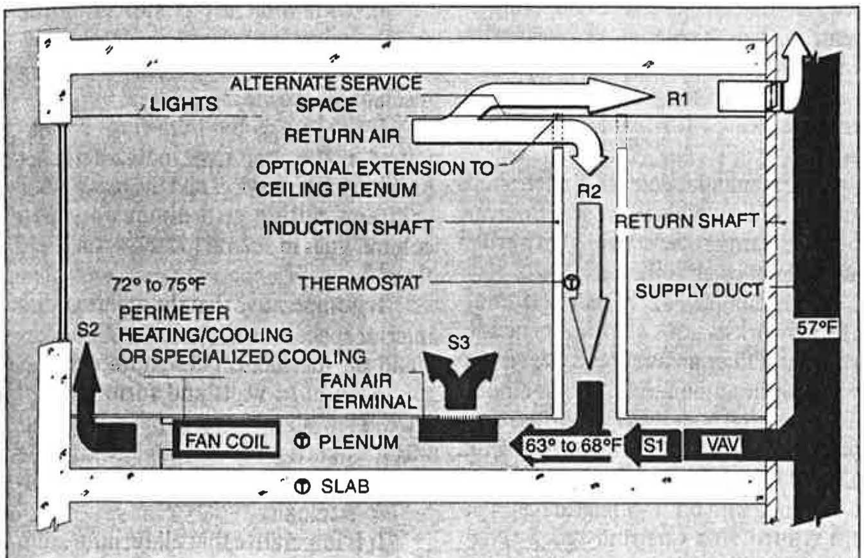

Figure 2. Air distribution schematic diagram.

control serves a large zone, between 3,000 to 10,000 ft^2 (279 to 929 m^2). Corridors, executive offices, meeting rooms and circulation spaces are moderated within the large zone by local temperature detection at thermostats that modulate the air terminals, drawing cool air from the plenum as required.

Occupants have manually controlled air terminals at their workstations. They adjust their comfort by the fan speed position (hence, volume of cool air) and the direction of air supply by rotating the directional grilles (if such are provided in their individual air terminals).

Occupants should be encouraged to adjust the volume (speed) to suit their needs but not to shut off the air entirely. People should also set the volume at mid-range when away from their workstations. A reasonable average circulation throughout an area is expected and is required for good overall control.

The air pattern from floor level provides complete space flushing. Conventional overhead distribution system air patterns (particularly in spaces with partial height partitions) are obstructed at the occupied levels.

Also, as a result of the reduced air temperature range, the space air circulation rate of the integrated system is up to double that of conventional systems. This provides a superior sense of air motion and better flushing and reduces the impact of intense local loads. The upflow air pattern encourages the natural thermal buoyancy of heat loads, returning some heat unneutralized to the return airstream and reducing the cooling capacity by as much as 15%.

The fan coil or heat pump units at the perimeter are used for perimeter ambient load neutralization. In addition, the fans help draw the supply air through the floor plenum to the perimeter, improving underfloor air mixing. At night, the fan coil (or heat pump) fans provide air circulation in the thermal storage modes as well as cycling to provide a setback level of heating.

The heating and cooling plants are configured similarly to conventional systems and, thus, are not illustrated. Air handling units (whether central or compartmentalized) are similar to conventional plants except for their lower operating pressures.

Figure 2 illustrates primary supply air being introduced to the access floor plenum at conventional temperatures. A recirculation airflow is driven by the perimeter units and the air terminals. This recirculation airflow return from the space mixes with the primary air to result in a mixed plenum temperature in the range of 63° to 68°F (17° to 20°C).

The perimeter system neutralizes ambient load influences, leaving all internal loads to be assigned to plenum air delivered through the air terminals. This simplifies the concepts for space conditioning, eliminating the design differences between perimeter and interior zones. The designer has one set of rules for all future design, leaving the perimeter units as a permanent building facility.

Experience with the prototype system has demonstrated that the central air handling performed satisfactorily. However, it required considerable care to set up

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because of the low operating pressures and the temperature-based VAV damper control. The compartmentalized air handling simplified the initial setup, provided greater flexibility in partial or after-hours operation, and provided minimum disruption to adjacent area operations during modifications.

Design guidelines

Studying the performance of the prototype system has lead to the following design principles that have influenced all subsequent designs.

Underfloor air mixing within the range of 63° to 68°F (17° to 20°C) is the most important design parameter.

To realize the benefits of mass storage, use precast concrete or a concrete-filled metal sandwich-type of access floor.

Locate underfloor ducts to minimize penetrations of access floor pedestals through the ductwork.

If vertical plenum space permits, detail an angle iron frame to span underfloor ductwork and perimeter units and avoid pedestal penetrations into the duct walls.

Do not attempt to separate sections of the underfloor into distinct plenums for air distribution. Any electrician can destroy the best sealed plenum in seconds.

Sprinklers are required in the access floor plenum unless the combustibility and smoke spread ratings of cable within the plenum are to acceptable standards or run in conduit.

Try to keep air terminals away from occupant circulation routes. People object to the different feel underfoot.

When locating space for return air paths to the access floor plenum, find locations that are permanent building elements, such as at columns or shafts adjacent to core walls.

Insist on proper placement of air terminals, at least 4 ft (1.2 m) from a workstation.

Select manual control air terminals that are understandable in use (indicate cooler or warmer). Select units with grilles that will not catch spike heels.

Use manual control air terminals only at workstations that are generally occupied. Other areas should depend on thermostatic automatic control methods.

Select the best available air terminal for comfort and aesthetic application. *Figure 3* illustrates two basic workstation outlets, one with both volume and air pattern control and one that has a fixed-pattern low draft diffuser.

For improved appearance, a linear grille air terminal or an underfloor fan for ducted applications (see *Figure 4*) may both be used but only with thermostats.

A promising new concept is illustrated in *Figure 5*, where air is supplied up a pivotal shaft among a cluster of workstations.

Manually controlled air terminals should be set with a minimum position between 30% and 50% full flow.

Assist your client in training the staff to use and appreciate the system's features.

Drain the floor plenums with sufficient removal capacity to meet sprinkler and fire hose delivery rates.

Application guidelines

Experience in construction has resulted in the following coordination considerations to ensure ease of tenant design and installation.

Ensure that all underfloor base building piping is installed at an elevation below the raised floor, which will allow the installation of air terminals above the piping.

Provide dimensions indicati exact location of ductwork installed the raised floor on the base bu mechanical drawings.

Insist that as-built drawings b mitted by the contractor indicating location of the services and the raise grid and ceiling grid dimension column lines in several locations on floor.

It is imperative that the archite interior space planning consultant u stand the mechanical design impac the location of walls and furnitur have. They should locate partition furniture such that there remains su and accessible space to locate the app ate air terminals.

It is imperative that all furnitur equipment (photocopier, filing cab etc.) be shown on the drawings pri starting the mechanical design. The layout determines the HVAC system figuration and location of devices.

Corridor partitions should line u the outside edge of the floor grid. Thi allow linear-type air terminals to be ins along the length of the corridors or the interior zone walls of the peri offices at the edge of the walls, whil being removable. Once a wall or pie furniture is positioned on a panel con ing an air terminal, that panel (and ai minal) can no longer be easily reloca

The experience with the proto system to date has been very encoura The system presently has good user a tance. Even during the commissio period, when many unavoidable prob were solved, a professionally cond user survey indicated equal or greater s faction with the integrated system as c pared to conventional VAV systems. feedback confirms even greater satis tion since then.

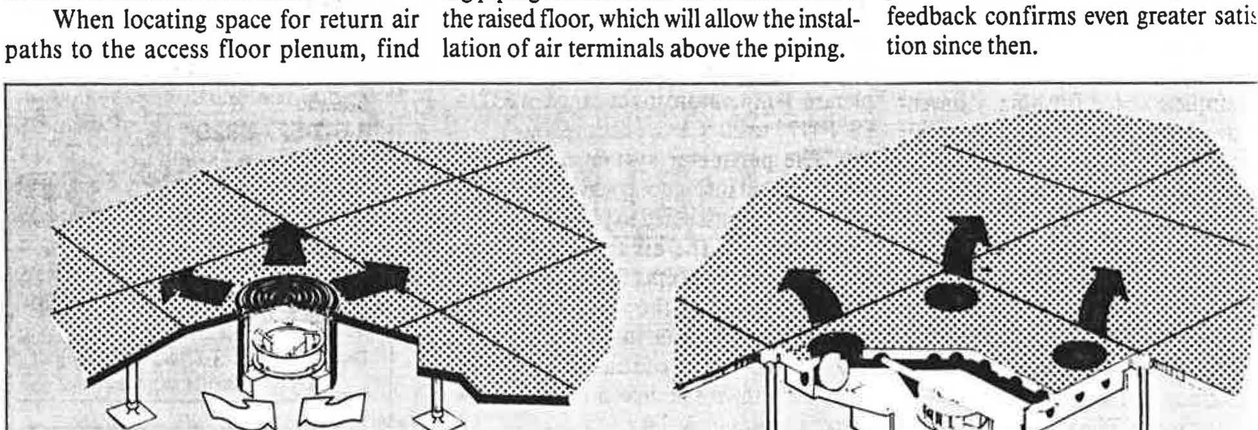

Figure 3. Workstation air terminals.

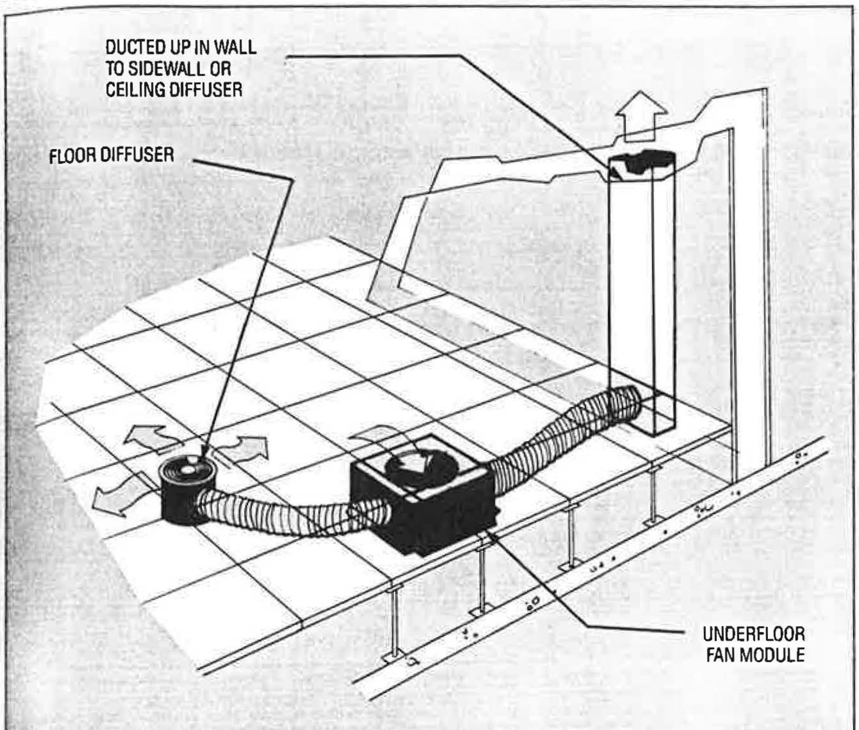

Figure 4. Underfloor ducted air terminal.

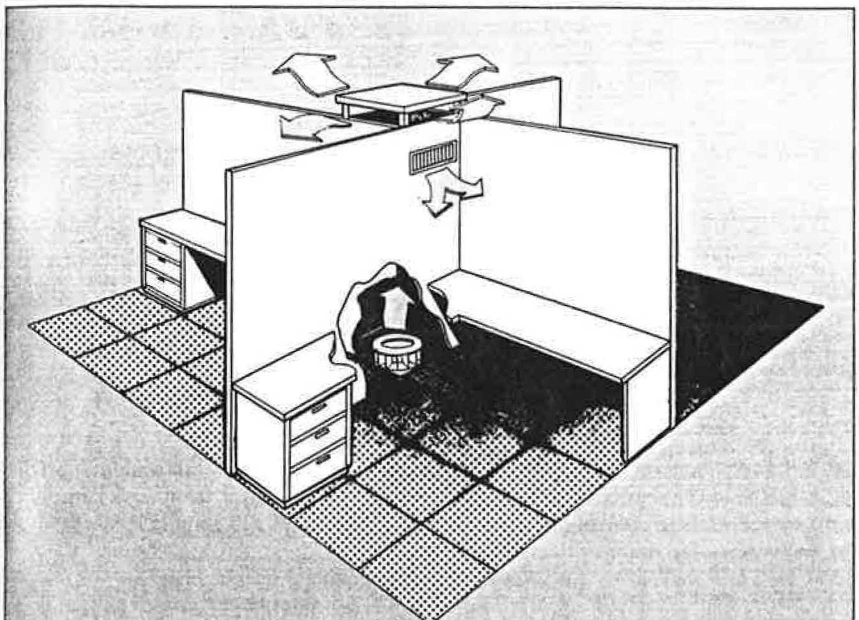

Figure 5. Furniture air terminal.

Future enhancements

The prototype project is continuously being analyzed for further improvements. Different air terminal designs and air patterns are being studied to enhance air delivery and control interface alternatives.

At present, the cost for the integrated access floor HVAC system appears to be competitive with conventional systems, if the cost of the access floor can be justified for other than HVAC uses.

The air terminal units, primary duct distribution, access floor and power distribution can be held back until just before turning the space over to the tenant, an interim financing saving. The developer of the prototype project believes a slight rental premium and greater market acceptance were received because of the integrated system.

With the expected evolution through greater use and experience, owners and tenants may anticipate capital and lifecycle cost savings with enhanced performance and flexibility. ■