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Underfloor Air Distribution Solutions for Open Office Applications

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ABSTRACT

The use of raised access flooring systems for office environments has become much more frequent in recent years. Power and data cables housed in the floor cavity can easily be accessed and modified to accommodate changes in the occupancy and use of the space. This cavity can also be used as a supply air plenum, which allows introduction of conditioned air through the floor. Unfortunately, most load calculation procedures and programs in use today are based upon overhead systems and do not afford the designer the tools necessary to properly assess the performance and economics of underfloor air distribution systems.

This paper discusses opportunities for improving space ventilation and reducing installation and operating costs that are inherent to underfloor air distribution systems. In addition, procedural differences in the determination of equipment requirements and operational efficiencies are identified and adjustments are suggested that allow application of load data obtained by existing methods to underfloor systems.

INTRODUCTION

The employment of raised access floors for office applications has increased rapidly over the past few years. Raised access floors allow the placement of power and data cables between the slab and raised floor panels, which enables wiring to be performed in a modular fashion. This eliminates the need for vertical columns to deliver the cables to the lower extremities of the room where receptacles are located. Most importantly, the modification of the space to respond to tenant or space utilization changes becomes much easier and less disruptive.

The cavity created by a raised floor system can often be used as a supply air plenum. The depth of the floor cavity for such applications is typically a minimum of 10 in. (0.25 m) so that a sufficient supply air path is maintained and volume control units may be located within the cavity. Although this depth requirement exceeds the 4 in. to 6 in. (0.12 m to 0.15 m) required for simple cable and wiring applications, the additional depth can generally be accommodated by reducing the ceiling plenum depth since ductwork and terminal units are no longer housed there. The ceiling cavity continues to be used as a return air plenum, however. The location of return outlets in (or near) the ceiling is paramount to deriving full benefit from an underfloor air distribution system.

Although relatively new to North America, underfloor air distribution has been successfully used in Europe and the Pacific Rim for more than a decade. The use of underfloor air extends the flexibility to accommodate space changes to the mechanical system as well as the electrical and communication systems. Supply air outlets can easily be added and/or relocated in response to such changes.

UNDERFLOOR AIR DISTRIBUTION SYSTEMS

Figure 1 illustrates a typical underfloor air distribution system in which interior spaces are supplied by a pressurized plenum and perimeter zones are partitioned and supplied by individual terminal units. Perimeter heat (in this example) is achieved by the employment of underfloor fan terminals that deliver the conditioned air through a baseboard finned-tube coil. Return outlets are located in the ceiling in order to facilitate a single vertical supply air pass.

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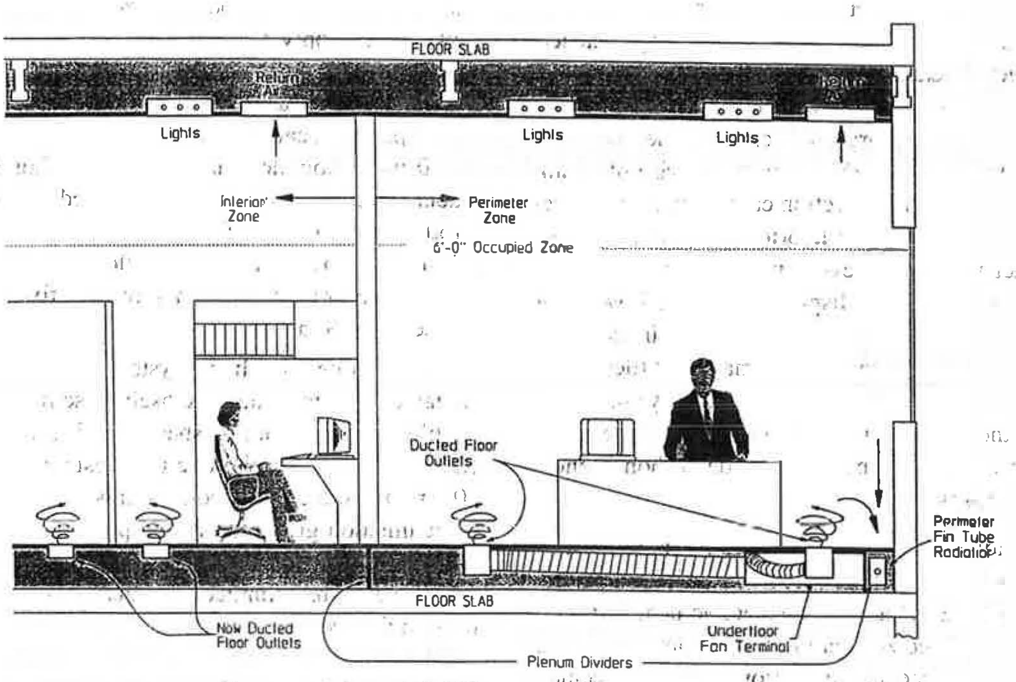

Figure 1 Typical underfloor air distribution system.

Overhead mixing type systems (see Figure 2) have been very popular for the conditioning of office space in North America. These systems supply conditioned air to the space by means of ceiling-mounted diffusers. These diffusers discharge air along the ceiling at 55°F to 57°F (13°C to 14°C) and are sized for sufficient outlet velocities to induce room air, mixing this with the supply air prior to entry into the occupied regions of the space. Most of the heat transfer between supply and room air occurs above the 6 ft (1.8 m) level. When properly selected, these outlets produce resultant room velocities in the 20 fpm to 30 fpm (0.10 m/s to 0.15 m/s) range throughout the occupied zone (the lower 6 ft or 1.8 m of the space). Proper outlet selection results in (1) little or no temperature gradient within the occupied zone, (2) return air temperatures (at the ceiling) that are similar to that of the room itself, and (3) similar contamination levels throughout the space (and in the return airstream) at design conditions.

Underfloor air distribution systems (also illustrated in Figure 2) typically supply air at discharge temperatures between 58°F and 63°F (14°C to 17°C) utilizing special high induction floor diffusers. This is particularly important as supply air is being introduced within the occupied regions of the space, so it is necessary that discharge velocities and temperatures be significantly reduced before occupants within

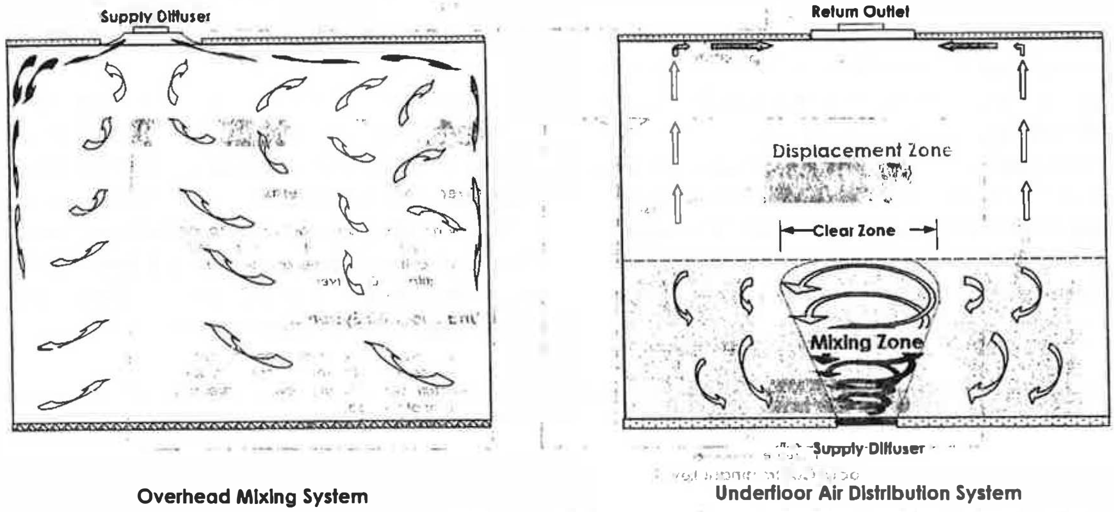

Figure 2 Overhead and underfloor air distribution systems.

the space are encountered. For this reason, outlet airflow is generally limited to about 100 cfm (47 L/s). Supply air jets leaving the outlets create mixed airflow conditions in the lower regions of the space; however, their mixing effect is minimized once the discharge velocity of the airstream reaches about 50 fpm (0.25 m/s). Any further rise of conditioned air is due to natural convection caused by heat sources within the space. The result is a hybrid system that incorporates two distinct vertical zones—a mixing zone within the lower levels of the space and displacement type flow in the upper zone. Although some horizontal variations in the velocity, temperature, and contaminant fields may exist (dependent primarily upon the location/contribution of supply outlets and heat sources in the space), these discrepancies are generally minor and the mixing zone may be considered homogenous for modeling purposes.

Two major advantages of this type of system are that (1) ventilation air is sure to reach the occupants (as it is introduced within the occupied zone) and (2) convective heat gains that occur above the occupied zone are isolated from the calculation of the required space supply airflow. The displacement type flow (of underfloor systems) that occurs in the upper zone serves to more efficiently convey airborne pollutants to ceiling-based exhaust openings, resulting in contaminant levels at the breathing levels of the space that are considerably less than those found in mixing type systems (see Figure 3). Japanese research (Kim and Homma 1992) estimates the ventilation effectiveness of underfloor systems to be about 1.1, independent of the supply airflow to the space. Overhead systems deliver this fresh air from locations that are typically 3 ft to 6 ft (0.9 m to 1.8 m) above the respiratory level of the occupants of the space and can only approach a ventilation effectiveness of 1.0 when complete mixing occurs. This effectiveness is reduced as the supply airflow is throttled. Studies indicate that throttling the supply airflow to 1.5 air changes per hour (typical of those found at minimum flow in variable-air-volume systems) may result in a ventilation effectiveness as low as 0.5 (Heiselberg 1996).

Underfloor air delivery systems may also employ a horizontal discharge strategy closely resembling displacement ventilation throughout the space. In this case, the mixing zone encompasses only a short vertical distance (typically 4 in. or 100 mm) above the floor. In this case, temperature and contamination gradients in the space are more pronounced. This strategy is most often applied in traffic areas where individual exposure is limited. The discussion of this strategy is beyond the scope of this paper.

MECHANICAL SYSTEM DESIGN FOR UNDERFLOOR AIR DISTRIBUTION

Effective employment of an underfloor air distribution strategy relies on consideration, quantification, and proper treatment of the two previously mentioned vertical zones. Unfortunately, the most commonly employed load calculation

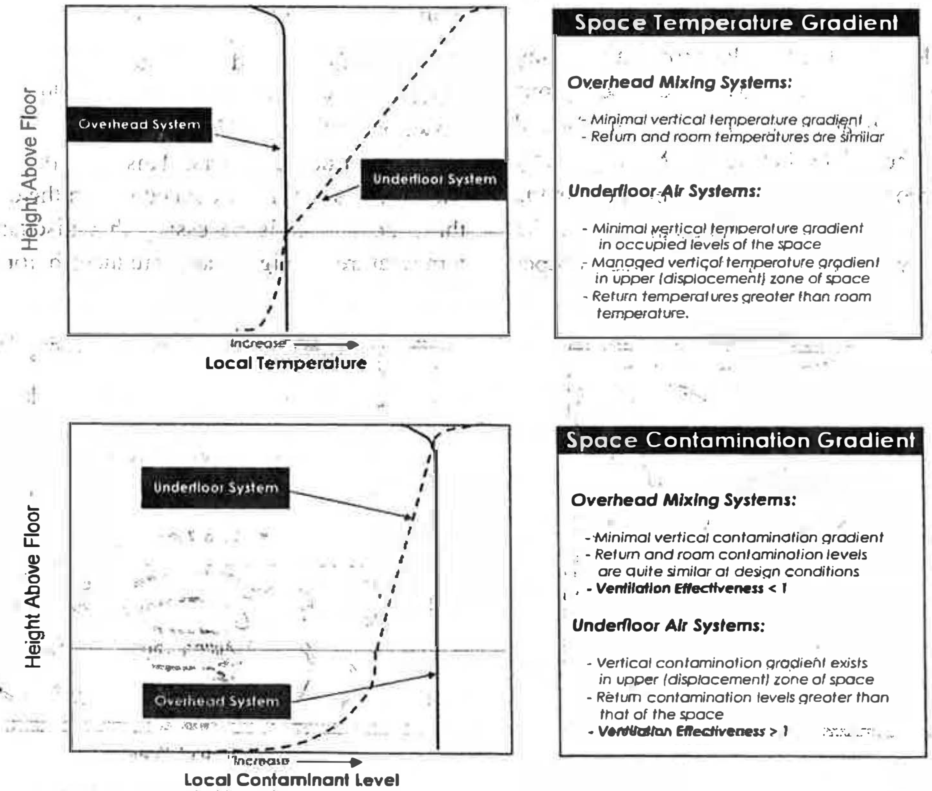

Figure 3 Performance comparisons—overhead vs. underfloor systems.

programs and procedures do not differentiate the location of individual heat sources within the space because they assume that a conventional mixing system (which thoroughly mixes all of the air and heat contribution within the space) is being employed. The following section will identify areas where overhead and underfloor system designs vary and recommend means by which these differences may be factored and properly reflected in equipment and operational cost predictions.

SPACE HEAT GAIN ANALYSIS FOR UNDERFLOOR AIR SYSTEMS

Underfloor air delivery through high induction floor outlets results in temperatures within the lower regions of the space that do not vary much; however, a distinct temperature gradient forms above this level. A single vertical pass of air through the upper regions of the space not only transports heat but also serves to remove airborne contaminants from the space. The lower region of the space has been designated as the *mixing zone*, and its vertical depth is defined by the height at which the supply outlet discharge velocity has been reduced to 50 fpm (0.25 m/s). Above this height (*M*), outlet velocities will no longer support mixing; therefore, air rises due to natural convection. Since this very closely resembles displacement ventilation, the vertical portion of the space from the top of the mixing zone to the ceiling is referred to as the *displacement zone*.

As outlets in an underfloor air system are tasked with introducing relatively high velocity cool air directly to the occupied zone, consideration must be taken that outlets are not located so close to stationary occupants that uncomfortable conditions would likely exist. This can generally be avoided by selecting and locating outlets such that no occupant is located within a radius of the diffuser where velocities in excess of 50 fpm (0.25 m/s) and temperatures more than 1°F (0.6 K) lower than that of the room (ASHRAE 1997c) are predicted. This horizontal radius can be obtained from most manufacturers' data and will be referred to as the outlet's *clear zone* (also depicted in Figure 3). The vertical depth of the mixing zone can usually also be derived from manufacturers' data.

Figure 4 references temperature gradients that may be expected (outside diffuser clear zones) in an underfloor air distribution system. European research on displacement air-conditioning systems (BSRIA 1993) has found that approximately 40% of the difference between supply and return air temperatures dissipates within 4 in. (0.1 m) of the floor. The assumption is that this is also basically true of underfloor air systems (except in the clear zone areas as described above). ASHRAE comfort criteria (ASHRAE 1997c) suggest that a temperature differential of 5°F (2.8°C) between the ankle (4 in. or 0.1 m level) and neck regions (4 ft or 1.2 m) of a seated occupant not be exceeded to thermally satisfy 90% of the polled population.

DETERMINATION OF SUPPLY AND RETURN AIR QUANTITIES AND TEMPERATURES

The required supply airflow of an underfloor system is a function of the total heat gain affecting space occupants; there-

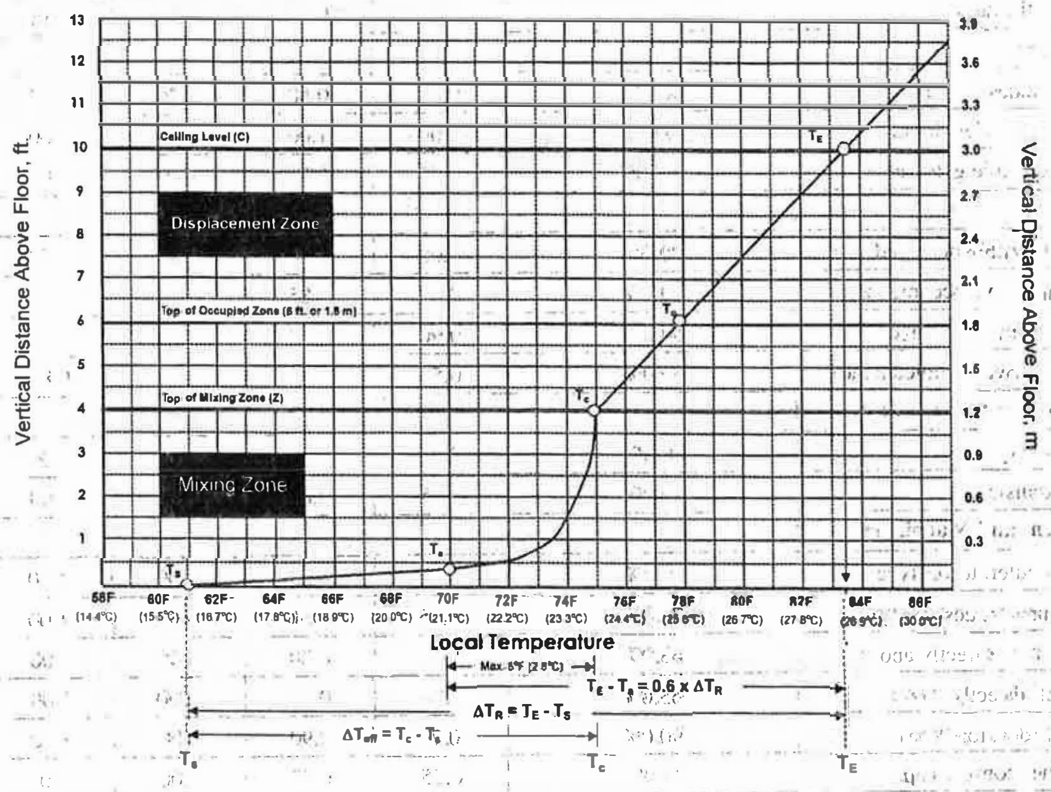

Figure 4 Vertical temperature gradient prediction for an underfloor system.

fore, calculation of the supply air requirement involves an accurate analysis of heat gains. Convective heat gains that originate outside the occupied zone may be neglected in calculation of this airflow as their convective heat currents rise naturally and need not be mechanically treated.

Table 1 recommends *effective heat gain factors (EHGFs)* that may be applied to space sensible heat gains to reflect this consideration. These factors have been empirically derived using data (ASHRAE 1997a, 1997b) documenting the radiative/convective split of common heat gain sources. While the entire radiant gain must be considered, the convective gain is analyzed and adjusted according to the percentage of its source that is physically resident within the mixing zone of the space. The EHGFs are then applied to the individual space heat gain sources to quantify their impact on the occupants in the space. The individual effective heat gains are then summed (see the example shown in Table 2) to determine the space *effective sensible heat gain (ESHG).*

The ratio of the ESHG to the *total sensible heat gain* (a summation of all sensible heat gains within the space) is used to determine the minimum supply air temperature (that which will maintain the 5°F (2.8°C) temperature gradient in the occupied zone) using Figure 5. This figure was created on the assumptions that (1) no more than 60% of the overall supply to exhaust air temperature difference occurs between ankle level and the ceiling (Jackman 1990) and (2) that the temperature gradient above the mixing zone is linear. The effective sensible heat gain is also used in the calculation of the required supply airflow to the space:

$$\text{Supply Airflow (cfm)} = \text{Effective Sensible Heat Gain (Btuh)} / (1.1 \times \Delta t)$$

where

Δt = temperature differential (°F) between the room air (at the 4 ft level) and the entering supply air (°F, as determined from Figure 5).

In SI units, this equation becomes

$$\text{Supply Airflow (L/s)} = \text{Effective Sensible Heat Gain (W)} / (1.232 \times \Delta t)$$

TABLE 1
Effective Sensible Heat Gain Factors for the Office Environment

Heat Source and Location	Percentage of Heat Gain that is Convective (% Total Heat Gain)	Effective Heat Gain Factor (EHGF), Height of Diffuser Mixing Zone: 4 ft (1.2 m)	5 ft (1.5 m)	6 ft (1.8 m)	7 ft (2.1 m)	8 ft (2.4 m)
Perimeter Walls and Glass						
Transmission through wall or glass	40.0%	0.77	0.82	0.87	0.91	0.96
Solar heat gain:						
Interior shades (blinds)	40.0%	0.60	0.68	0.76	0.84	0.92
No interior shades (blinds)	0.0%	1.00	1.00	1.00	1.00	1.00
Infiltration (sensible gain only)	100.0%	1.00	1.00	1.00	1.00	1.00
Lighting						
Incandescent (within occupied zone)	20.0%	1.00	1.00	1.00	1.00	1.00
Incandescent (above occupied zone)	20.0%	0.80	0.85	0.90	0.95	1.00
Fluorescent (within occupied zone)	50.0%	0.90	0.95	1.00	1.00	1.00
Fluorescent (above occupied zone)	50.0%	0.50	0.60	0.70	0.80	1.00
People (Sensible Heat Gain Only)						
Seated (stationary)	40.0%	0.70	0.85	1.00	1.00	1.00
Standing or transient	40.0%	0.55	0.65	0.85	1.00	1.00
Office Equipment and Machinery						
Personal computer, tower type	70.0%	1.00	1.00	1.00	1.00	1.00
Personal computer, desktop type	70.0%	0.65	0.80	0.95	1.00	1.00
Monitor, no shelf directly above	63.0%	0.65	0.80	0.95	1.00	1.00
Monitor, shelf directly above	63.0%	0.80	0.90	1.00	1.00	1.00
Laser printer (desktop type)	90.0%	0.75	0.90	1.00	1.00	1.00
Copy machine (console type)	85.0%	0.75	0.90	1.00	1.00	1.00
Facsimile machine (desktop)	90.0%	0.75	0.90	1.00	1.00	1.00

TABLE 2
Space Sensible Heat Gain Analysis

Heat Source and Location	Space Total Sensible Heat Gain Btu/h	Space Total Sensible Heat Gain W	Effective Sensible Heat Gain Factor	Space Effective Sensible Heat Gain Btu/h	Space Effective Sensible Heat Gain W
Perimeter Walls and Glass					
Transmission through wall or glass	20812	6100	**0.77**	**16025**	**4697**
Solar heat gain					
Interior shades (blinds)	40637	11911	**0.60**	**24382**	**7146**
Lighting					
Fluorescent (above occupied zone)	107136	31402	**0.50**	**53568**	**15701**
People (Sensible Heat Gain Only)					
Seated (stationary)	35770	10484	**0.70**	**25039**	**7339**
Office Equipment and Machinery					
Personal computer, desktop type	24050	7049	**0.65**	**15633**	**4582**
Monitor, no shelf directly above	34450	10097	**0.65**	**22393**	**6563**
Laser printer (desktop type)	79950	23433	**0.75**	**59963**	**17575**
Copy machine (console type)	24000	7034	**0.75**	**18000**	**5276**
Facsimile machine (desktop)	1200	352	**0.75**	**900**	**264**

Space Total Heat Gain	Total Sensible Heat Btu/h	Total Sensible Heat W		Effective Sensible Heat Btu/h	Effective Sensible Heat W
Space Total Heat Gain	368005	89852		235902	57299

Effective Sensible Heat Gain (% of Total Sensible Heat Gain)	**64.1%**

Note: Example shown is based on an intermediate floor of a multistory building designed for Chicago, Ill.:

1) Outdoor design conditions are 91°F (33°C) dry bulb, 74°F (23°C) wet bulb. Indoor design is 75°F (24°C) and 50% RH.
2) People, lighting, equipment and pe imeter zone skin loads are as follows:
   a) Occupancy based on an average of 88 ft^2 (8.2 m^2) per person, resulting in a sensible load of 2.75 Btuh/ft^2 (8.7 W/m^2)
   b) Lighting load used is 3.5 W/ft^2 or 12 Btuh/ft^2 (37.9 W/m^2)
   c) Equipment loads average 12.7 Btuh/ft^2 (40 W/m^2)
   b) Perimeter zone skin loads average 12.5 Btuh/ft^2 (39.4 W/m^2)
3) Effective heat gain factors shown are based on a 9 ft (2.74 m) ceiling and a 4 ft (1.2 m) diffuser mixing zone.

where

Δt = temperature differential (°C) between the room air (at the 1.2 m level) and the entering supply air (°C, as determined from Table 1).

Once the supply air temperature and volume have been determined, the return air temperature (typically several degrees higher than that of the room) can be predicted:

Return Air Temperature (°F) =
$$\text{(Space TSHG)} / (Q_S \times 1.1) + T_S \text{ (°F)}$$

In SI units,

Return Air Temperature (°C) =
$$\text{(Space TSHG)} / (Q_S \times 1.232) + T_S \text{ (°C)}$$

where

TSHG = total sensible heat gain, Btu/h (W);

Q_S = supply airflow rate, cfm (L/s);

T_S = supply air temperature, °F (°C).

While it is not pertinent to other space calculations, accurate identification of the return air temperature and moisture level is important because it is used in the calculation of the inlet (mixed) air conditions at the air-handling unit. These parameters are major determinants of the required refrigeration capacity of the system.

ADVANTAGES OF UNDERFLOOR AIR SYSTEMS

Underfloor air distribution systems offer savings opportunities that affect both initial equipment sizing and mechanical system operational costs. In addition, space ventilation and flexibility benefits are also inherent with these systems.

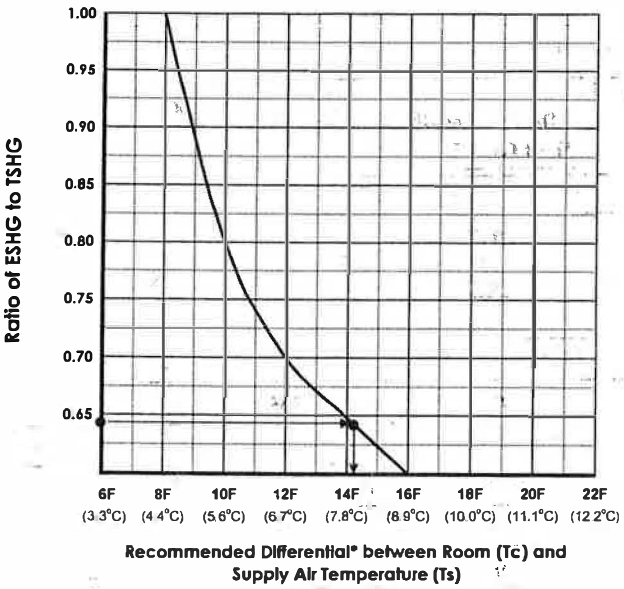

Figure 5 *Supply air temperature determination. Note: Differentials shown are maximum allowable in order to maintain a temperature difference of no more than 5°F (2.8°C) between the 4 in. (0.1 m) and 4 ft (1.2 m) level of the space.*

The following subsections identify some of these savings and benefits (summarized in Table 3).

MECHANICAL EQUIPMENT SIZING

Underfloor system supply fan capacity requirements are typically reduced (over conventional overhead systems) when diffusers are selected and sized such that their mixing zone depth does not exceed 5 ft (1.2 m). The amount of reduction to be expected is inversely proportional to the depth of this zone. Reduction or elimination of much of the ductwork beyond the terminal units is common in underfloor systems, which results in reduced downstream static pressures. The educed airflow and higher return air temperatures inherent to underfloor systems often lead to lower required refrigeration equipment capacities as well.

Finally, terminal unit and terminal reheat coil capacities are reduced due to the lower supply air requirements, although their costs may not be significantly reduced since physical size restraints often limit their capacity accordingly.

REDUCED OPERATIONAL COSTS

Numerous operational cost advantages are inherent to underfloor air systems. The previously cited reductions in supply fan airflow and static pressure result in substantial air moving operational cost reductions. In addition, other mechanical system operational cost reduction opportunities exist.

1. *Improved Chiller Efficiencies.* Since underfloor systems

TABLE 3
Summary of Underfloor Air Advantages

Advantages	Explanation and Comments
Improved Space Ventilation	1. Single vertical passage of supply air through the occupied zone transports heat and removes airborne contaminants from space.
	2. Introduction of ventilation air through the floor ensures its delivery to the space occupants.
	3. Occupants are afforded control over the delivery of the outlets within their work space.
Reduced Mechanical Equipment Costs	1. The single vertical air passage isolates convective heat gains that occur above the occupied space, eliminating them from supply airflow calculations. This results in supply fan airflow requirement reductions of as much as 20%.
	2. Most or all of the ductwork downstream of zone terminal units is eliminated. This also results in lower fan static pressure requirements.
	3. System refrigeration requirements may be reduced as the percentage of exhausted return air is increased.
Reduced Operational Costs	1. The reduced fan airflow and pressure requirements result in lower fan horsepower requirements, thus reducing mechanical ventilation costs.
	2. The increased supply air temperature of underfloor systems results in higher chiller return water temperatures and substantially higher chiller efficiencies.
	3. Periods of "free cooling" are extended due to the higher supply air temperatures inherent to underfloor systems. This is particularly attractive in areas of mild climate.
Enhanced Space Flexibility	1. Outlets can be easily relocated to accommodate changes in the space and in response to occupants' individual preferences.
	2. Outlets can be easily added and/or relocated in response to changes in tenants or use of the space.
	3. Outlets can be added and/or relocated to accommodate increases in space sensible loads.

correspondingly higher. Higher return water temperatures allow the chiller to operate at efficiencies up to 40% greater (Houghton 1995), resulting in proportional operational cost reductions.

2. *Periods of "Free Cooling" are Extended.* As the supply air temperatures for underfloor systems are higher (see above) than conventional overhead systems, periods of "free" cooling are extended. This is of particular benefit in relatively mild climates.
3. *Perimeter Reheat Requirements are Reduced.* Reduced airflow requirements and higher supply air temperatures of underfloor systems result in reduced reheat requirements (as the temperature difference between supply and room air is less).

IMPROVED SPACE VENTILATION AND OCCUPANT COMFORT

Underfloor air distribution systems are more effective in ventilating open office spaces than their overhead counterparts. Ventilation air (delivered through the floor) is mixed within the occupied zone then escapes along a vertical path to overhead return outlets, resulting in ventilation effectiveness ratings in excess of 1.0 regardless of the supply airflow. Contaminant levels in the exhausted air always exceed those of the space.

Open office areas generally include partitions that surround workstation areas. These areas may be as small as 60 ft^2 (5.6 m^2) and house a single occupant. Overhead systems often attempt to supply 300 ft^2 to 600 ft^2 (28 m^2 to 56 m^2) of floor space (five to ten office cubicles) with a single supply diffuser. These partitions restrict room air movement, effectively eliminating any possibility that the supply and room air will become sufficiently mixed to eliminate stagnation and properly ventilate the occupied space. Underfloor air distribution systems allow supply outlets to be placed directly within each workstation, ensuring that ventilation air is delivered to each occupant and room air movement is maintained.

Finally, floor-based systems offer provisions for the accommodation of individual occupant comfort. The location of the outlets makes them very accessible for occupants to adjust them to their personal preference. The employment of the pressurized floor plenum ensures that these adjustments may be accomplished with minimal effect on the rest of the air distribution system.

ENHANCED SPACE FLEXIBILITY

Owners demand raised access floor systems due to the flexibility they offer. Relocation of power and data cables in response to space changes may be accomplished quickly and easily, resulting in minimal interruption to workers and processes within the area. This flexibility, however, does not come without a price. Raised access floor systems may result in a 5 US$ to 7 US$ per square foot additive cost over conventional flooring. Utilization of an underfloor air distribution strategy expands this flexibility to the mechanical system where relocation problems of supply outlets potentially dwarf those of an electrical system. In addition, much of the additive cost of the raised floor system may be offset by the previously cited reductions in mechanical system installed costs that are inherent to underfloor systems.

When pressurized plenums are utilized, floor outlets can be added, removed, or relocated by simply removing, repositioning, and/or replacing the floor tile in which they are mounted! This allows the space airflow delivery to be modified to accommodate changes resulting from the following:

1. *Changes in Space Configuration and/or Utilization.* Outlets can be moved in response to relocation of partitions and/or occupants within the space. This often involves nothing more than relocating the active floor tiles that contain supply outlets and/or cable receptacles.
2. *Changes in Space Equipment or Occupancy Loads.* Addition or relocation of space equipment and/or occupancy loads can often be accommodated by adding outlets. Since the addition of a supply air outlet only involves tapping it into the supply air plenum, minor changes can often be accomplished by adding or relocating active floor tiles and making minor adjustments to the terminal units serving the space. Substantial changes may involve adjustment of the supply air fan and/or refrigeration equipment but still result in minimal space disturbance.
3. *Personal Occupant Comfort Accommodation.* Supply outlets can be added, removed, or relocated to suit individual preference. Outlets may also be moved to adapt to individual office rearrangements (addition/movement of furniture, etc.) performed by the occupants.

UNDERFLOOR AIR DISTRIBUTION SYSTEM DESIGN CONSIDERATIONS

Underfloor air distribution offers the designer a number of opportunities for equipment and operational cost savings when applied to an open office environment. In addition, owners and occupants stand to benefit from the improved space ventilation and flexibility that is inherent to the system. In order to realize the full benefit of an underfloor air system, certain considerations should be made.

1. *Use high-efficiency mixing type floor diffusers.* The selection of floor diffusers should be based on the depth of the diffuser's mixing zone and the radius of the clear zone. The mixing zone depth is critical for creating the upper level stratification necessary to efficiently isolate space convective loads. Selecting a diffuser with a mixing zone depth greater than about 5 ft will usually not allow sufficient load isolation, resulting in significantly higher supply airflow requirements. A mixing zone depth of 4 ft to 5 ft (1.2 m to 1.5 m) is considered optimal for office space applications where stationary occupants are seated. Diffuser clear zone radii should be minimized because this represents the distance at which diffusers should be located from station-

ary space occupants. Increased clear zone radii make proper location of outlets more difficult and limit their potential relocation because it reduces the space that may be comfortably utilized.

2. *Use the lowest supply air temperature that still results in high comfort levels.* Floor diffusers that have small clear zones confine their supply air jet to a small area where uncomfortable conditions are likely to exist. Outside this area, the supply air has been sufficiently mixed with room air to eliminate the potential for such conditions. The supply air temperature in an underfloor system is the predominant determinant of the required supply airflow quantity, so unnecessary elevation of the supply air temperature will result in higher supply airflows, more outlets, and less clear space!

3. *Do not overestimate the required supply air quantity.* The single most common complaint (heard by this author) regarding underfloor systems is that actual return air temperatures are in fact lower than the designer expected. This is invariably due to the fact that the required supply airflow was overestimated! The return air temperature is a function of the supply air quantity (and temperature) and the space total heat gain. Adding a generous "safety factor" to the calculated supply air quantity results in a lower return air temperature and, thus, inefficiencies in the conditioning of the space.

4. *Consider using fan terminals with reheat capabilities in perimeter zones where cold downdrafts (from windows) are expected during heating season.* Although it is advantageous to limit the vertical projection of the supply airstream while cooling from the floor (for load isolation purposes), it may be necessary to increase the supply air penetration when cold perimeter downdrafts exist. Underfloor fan terminals that induce (and reheat) room air and discharge it up the wall should be considered for such applications.

5. *Consider using booster fan terminals for spaces with rapid (cooling) load shifts.* Despite all their virtues, underfloor systems are relatively passive when subjected to rapid load shifts that might be expected to occur in conference areas and other spaces with rapid load shifts. In these spaces, use of a booster fan terminal (which draws air from the underfloor plenum) can supplement natural system response.

6. *Make sure the underfloor terminals' widths do not exceed 22 in. (0.56 m).* Raised access floors generally use panels that are nominally 24 in. (0.61 m) square. Support pedestals, which are located at each corner, extend from the floor slab to the bottom of the floor panels. Terminal units should be sized to fit between these pedestals and within the prescribed floor cavity depth.

CONCLUSIONS

Raised access floor systems have become increasingly popular for use in open office applications due to the space flexibility they offer in terms of the relocation of power and data cabling. Underfloor air distribution systems utilize the cavity created by the raised floor as a supply air plenum, extending the flexibility of the access floor strategy to the mechanical system. The resultant air delivery system can be easily modified to accommodate space and/or tenant changes while providing improved space ventilation. Numerous installed and operational cost saving opportunities are inherent to these systems. Table 3 summarizes some of the benefits of underfloor air distribution.

In order to maximize these opportunities, certain considerations and modifications should be applied to the design and load analysis procedures. This paper has attempted to identify some of these considerations and establish methods for applying conventionally generated cooling loads to underfloor air distribution systems.

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