Designing HVAC Systems for Optimum Indoor Air Quality

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Abstract

HVAC system designs must address both high indoor air quality as well as energy efficiency as the awareness of and demand for proper air quality increases. Economic considerations such as installation and operating costs have impaired many conventional system designs to the point of compromised indoor air quality. This paper discusses many HVAC design parameters that are critical to achieving adequate indoor air quality. Topics include location of building fresh air intakes and exhaust air outlets, economizer systems, airflow tracking, filtering systems, sound attenuation, humidification systems, room air distribution, coil drain pans and condensate traps, duct zoning, localized exhausts, and temperature and humidity control.

Introduction

Because of combined effects of decreased ventilation rates and tighter building construction to produce "energy-efficient" buildings, as well as increasing volumes and types of building generated air pollutants, many buildings are experiencing problems with indoor air quality.

Indoor air quality awareness is increasing rapidly as more information is made available on contaminant detection, resulting health hazards, and the cost of poor productivity and/or litigation because of sick or uncomfortable workers.

In the past, energy efficiency was the primary design driver. However, today HVAC system designers must respond with system solutions that offer both high indoor air quality as well as energy efficiency.

Systems that are both energy efficient and promote healthy environments are realized through careful consideration of design parameters that directly affect indoor air quality. These include the proper use of economizers, variable air volume systems, airflow measurement, air filters, humidification, drain pan design, and sound attenuation. Also included are many design options that, when considered collectively during preplanning stages, can significantly improve indoor air quality throughout the life of a building.

Indoor Air Quality

In the past, HVAC systems adapted well to the energy crunch by implementing designs for greater energy-efficient operation. Considering that almost 10 percent of the total U.S. energy consumption is attributed to heating, cooling, distributing, and otherwise processing ventilation air for buildings, it is no surprise that most designs meant a reduction in ventilation (ASHRAE, 1987).

Evolving with such reduced ventilation systems were new building materials and furnishings that incorporated contaminants, such as formaldehyde. In addition, new buildings were being designed for very low air leakage, with permanently closed windows.

Published information on the health hazards, combined with improved instrumentation to detect contaminants, has resulted in workers who are more aware of their indoor air quality (IAQ).

Because a business' cost of conditioning building air is about $2 per square foot, while the cost of an adequately productive work force is about $150 per square foot, the economics of indoor air quality are gaining importance.

Many indoor air contaminants stem from a building's every day use such as copy equipment exhaust, cleaning solvents, floor waxes, aerosols, radon gas, cosmetics, smoking, and human body odor. Volatile organic compounds (VOCs), which are produced from synthetic furnishings, carpets and some building materials, also are a problem in maintaining IAQ.

In addition, the HVAC system itself adds to the IAQ problem with dust and microbe accumulation in filters, duct linings, cooling coils, drain pans, and humidifiers. Other causes of IAQ contaminants may be the location of outdoor air intakes, which results in the introduction of automotive exhaust, or an inadequate outdoor air supply volume, which results in CO^2 and other contaminant build-up (see Figure 1).

Figure 1
Common Causes of Indoor Air Quality Complaints

Ventilation Systems	48.3 %
Inside Contamination (other than smoking)	17.7 %
Contamination from Outside Sources	10.3%
Poor Humidity Control	4.4%
Contamination from Building Materials	3.4%
Hypersensitivity (Pneumonitis)	3.0%
Cigarette Smoking	2.0%
Other or Unknown	10.9%

Source: National Institute for Occupational Safety and Health (NIOSH)

Because occupant- and building-generated contaminant sources are difficult to eliminate, remedies are directed at contaminant dilution and removal. In contrast, HVAC system-generated contaminants are more easily controlled through proper system design, which actually removes the pollutant source.

Conventional energy-efficient HVAC systems with minimal ventilation keep indoor air contaminants recirculating in building air. This results in higher concentrations of internally generated pollutants.

The fact that "Sick Building Syndrome" (defined when more than 20 percent of a building's occupants have illnesses such as respiratory infections, headaches, and eye irritations perceived to be caused by indoor air contaminants) is now a well known term means that companies and their employees are aware of the standards they want in IAQ.

Consistently achieving adequate IAQ over the long term requires thoughtful analysis of the many IAQ contaminant countermeasures.

Some straightforward countermeasures include adequate outdoor air ventilation, clean air filters, and properly pitched and trapped cooling coil drain pans. Other countermeasures require more pre-planning such as installing means to isolate building ventilation zones where building renovations may take place, planning for office equipment and its direct exhaust, and measurement of outdoor air intake to assure a minimum standard while maintaining heating/cooling economy.

The best HVAC design for achieving adequate IAQ is one that considers all possible countermeasures and their contribution to both a healthful and energy-efficient environment.

Outdoor Air Intakes

A first step in achieving high quality indoor air is to start with high quality outdoor air for building ventilation.

Substantial progress has been made in the improvement of outdoor ambient air quality through research and regulatory activity aimed at the environment and industry (ASHRAE, 1987). The Environmental Protection Agency, the National Institute for Occupational Safety and Health, as well as state and local authorities monitor air quality and conformance to air quality standards. These standards include limits for sulfur dioxide, carbon monoxide, ozone, nitrogen dioxide, lead, and total particulate counts in outdoor air (see Table I) (ASHRAE, 1989).

However, conforming to standards alone is not enough. To some building occupants, odors from a nearby fast-food restaurant may be quite noticeable and bothersome, and complaints may quickly mount. One means to minimize several possible outdoor air contaminants is to locate properly outdoor air intakes. Thoughtful design of outdoor air intakes can reduce the need for costly outdoor air treatment and cleaning systems in the future (see Figure 2).

Some items to consider are: odors from restaurants, beauty salons, and laundries; roadway, gas station, parking garage, and "drive-up" carbon monoxide exhausts; and sulfur exhausts from landfills and garbage dumps.

Nearby undeveloped lots should be considered with respect to lot zoning and the type of business that may appear there in the future. Other more subtle intake contaminants to consider include bird nests with associated fecal material, the proximity of cooling towers, and standing water such as a pond that may produce odors and airborne microbes (Meckler, 1991).

In addition, the location of outdoor air intakes should ensure that no cross contamination from the same building's exhaust will be possible.

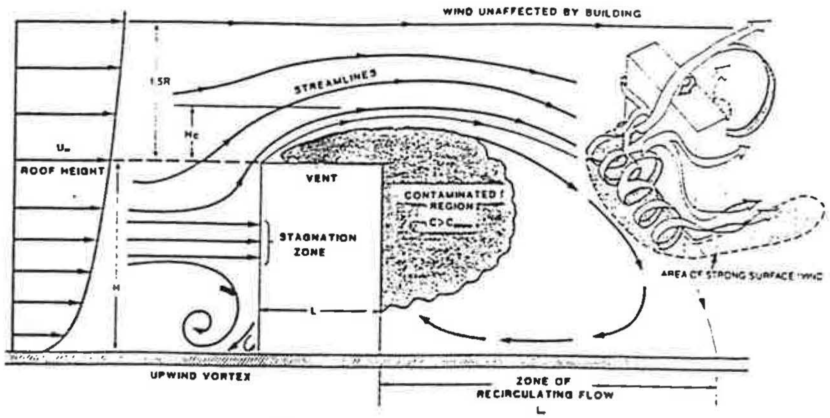
Table 1
National Primary Ambient-Air Quality Standards for Outdoor Air As Set by the U.S. Environmental Protection Agency

Contaminant	Long Term Concentration ug/m³	Long Term ppm	Long Term Averaging	Short Term Concentration ug/m³	Short Term ppm	Short Term Averaging
Sulfur dioxide	80	0.03	1 year	365	0.14	24 hours
Total Particulate	75[a]	—	1 year	260	—	24 hours
Carbon monoxide				40,000	35	1 hour
Carbon monoxide				10,000	9	8 hours
Oxidants (ozone)				235[b]	0.12[b]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months[c]			

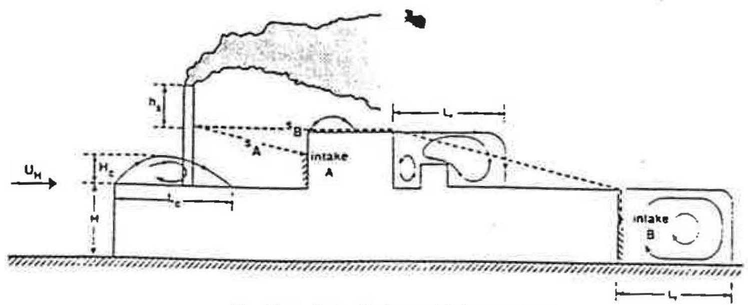
[a] Arithmetic mean

[b] Standard is attained when expected number of days per calendar year with maximal hourly average concentrations above 0.12ppm (235 ug/m^3) is equal to or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50

[c] Three-month period is a calendar quarter.



Flow Patterns Around a Rectangular Building



Flow Recirculation Regions and Exhaust to Intake Stretched String Distances (Wilson 1982)

Figure 2
(Source: 1989 ASHRAE Handbook—Fundamentals)

Economizer Systems

Although effective in reducing operating costs with respect to cooling building air, some economizer designs do not include provisions for maintaining required minimum outdoor air ventilation or outdoor air purge capabilities.

Before 1989, the ASHRAE standard for minimum outdoor air ventilation for office occupancies was five cubic feet per minute (cfm) per person. However, the standard is now at 20 cfm per person for office occupancies, 25 cfm for hospital patient rooms, and 30 cfm for operating rooms (ASHRAE, 1989 and Roberts, 1991). This fourfold increase in the minimum standard has left many existing economizer designs operating below adequate ventilation levels (see Figure 3).

For example, during ambient outdoor temperatures in the 50°F to 60°F range, the economizer opens outdoor air dampers achieving ventilation levels far above the minimum requirements for outdoor air intake per person. However, during higher or lower outdoor temperatures where cooling or heating energy is required, the economizer unit restricts outdoor air dampers electing to re-cool the building's return air.

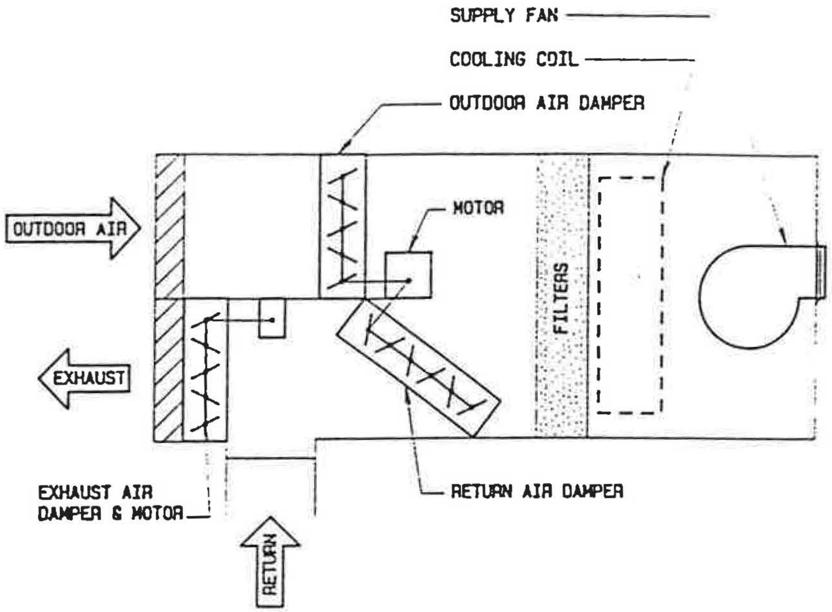
Figure 4 depicts a standard commercial rooftop economizer design containing return, exhaust, and outdoor air dampers and a supply fan. A fault in this design is the lack of an exhaust or return fan and the resultant inability to assure minimum ventilation and effectively purge building air with outdoor air.

Figure 3
Outdoor Air Requirements for Ventilation*

Room Type	Outside Air
Hotel Guestroom	30 CFM
Office Space	20 CFM
Reception Area	15 CFM
Theater	15 CFM
Classroom	15 CFM
Library	15 CFM
Hospital	
Patient Room	25 CFM
Operating Room	30 CFM

* *According to American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) ventilation standards.*
(CFM = Cubic Feet of Outdoor Air per Minute)

Figure 4
Standard Commercial Rooftop Economizer Arrangement



Purge capability is desired for emergencies such as smoke exhaust, but in other, less urgent situations, purge capability can economically support IAQ by flushing out space contaminants. For example: a weekend or evening purge with no heating or cooling required in an unoccupied building or purging after a building renovation has been completed to rapidly remove construction material contaminants.

In addition, an exhaust or return fan allows more control in maintaining proper building pressurization and assures proper economizer operation. Without a return or exhaust fan, the economizer system relies on space pressurization to "push" the exhaust through the air return system and economizer exhaust damper. More often than not, this is not possible, and the economizer never operates as intended.

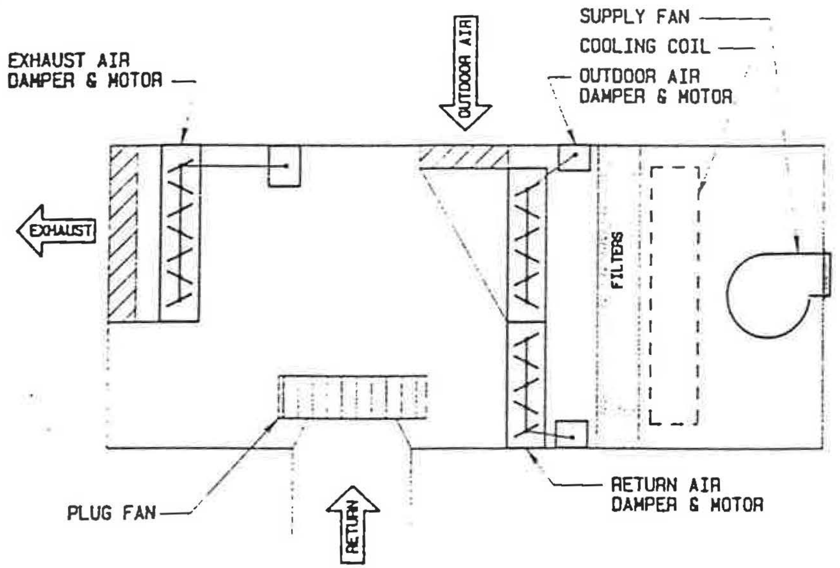
An exhaust fan offers purge capability, proper building pressurization, and proper economizer operation. One design option is a special fan arranged to accomplish both exhaust and/or return for purge and pressure control capability. Figure 5 is an alternative using a conventional plug fan. This design provides the most efficient, precise economizer operation. In economizer installations where minimal outdoor air is employed, the double fan action assures that enough return air is exhausted for the amount of outdoor air intake desired.

Airflow Tracking

The use of variable air volume (VAV) systems results in fluctuations of outside air intake similar to that of economizers. When demand for cooling is lower, VAV controllers reduce the flow of supply air so that the desired space temperature is maintained and less energy is expended in transporting the air.

However, the reduction of supply airflow results in a proportionate reduction in outdoor air intake. Because of the many factors involved, including the use of air-side and water-side economizers as well as building leakage, the actual amount of outdoor air supplied to a space may not be precisely calculable. At lower airflows, a minimum outdoor air intake of 20 cfm per person may be inadvertently compromised.

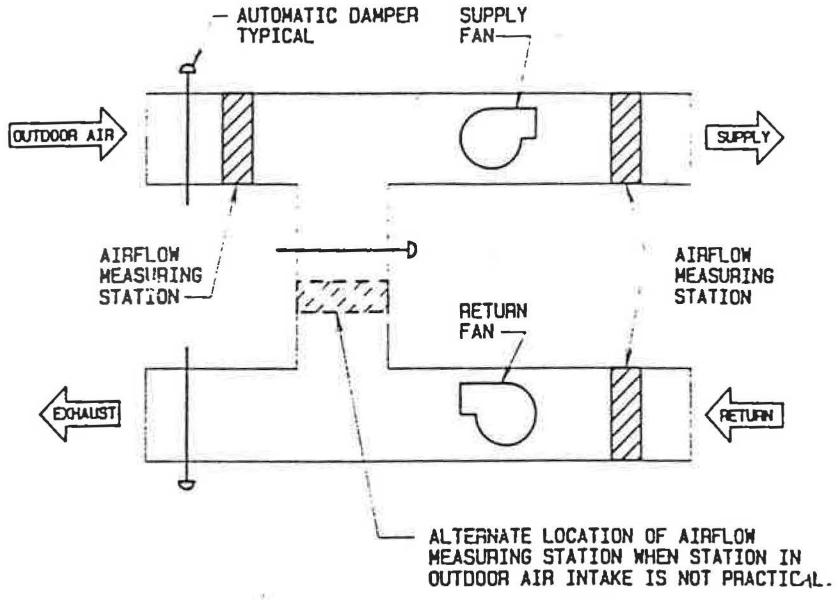
Figure 5
Alternate Commercial Rooftop
Economizer/Return-Exhaust Fan Arrangement



For example, on a design day, a VAV system takes in 20 percent outdoor air. Building cooling requires a supply flow of 10,000 cfm. With decreasing outside temperature, building cooling load is lower; therefore, the VAV system reduces the supply flow to 5,000 cfm. Outdoor air intake is now reduced to 10 percent or less, which may not be sufficient to assure the minimum ventilation rate of 20 cfm per person.

One way of tracking outdoor air is to measure the CO^2 levels in occupied spaces. High CO^2 levels indicate inadequate ventilation. However, using CO^2 levels to control ventilation rate is difficult at best. A much more effective method is to employ a VAV system design which incorporates airflow measurement devices (see Figure 6).

Figure 6
Typical Location of Airflow Measuring Stations
In a Conventional Air Handling System



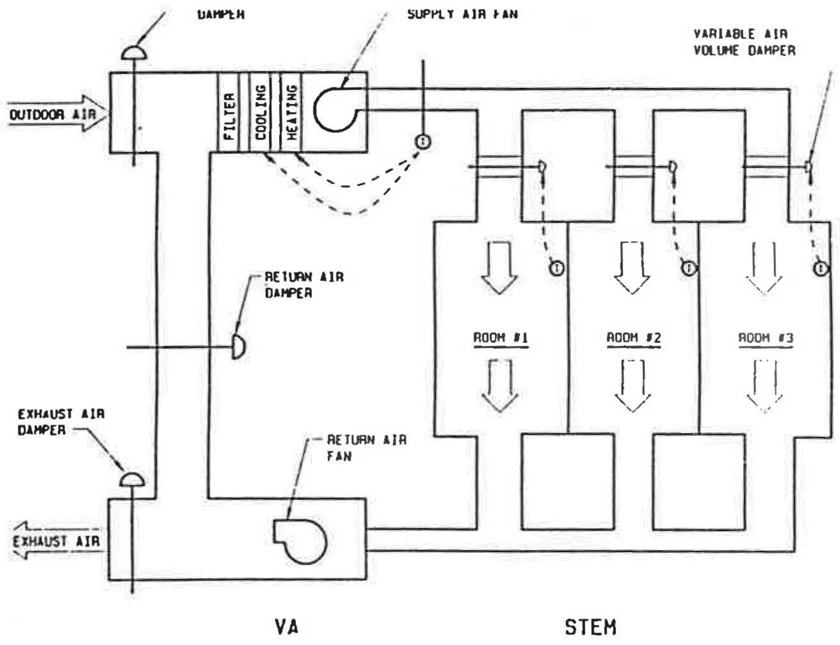
A measuring station in the outside air intake is first to measure actual flow against required flow and to alert an operator when below that limit.

Additionally, measuring stations in the supply and return systems, in combination with an intake measuring station, provide complete data on building pressurization as well as minimum ventilation airflow. When an outdoor airflow measuring station cannot be located physically within the outside air intake, an option is to place a station in the return to the mixing box, in addition to the supply and return air stations, so that outside air flow can be calculated.

Constant Volume with Reset Control

The air flow tracking system described above allows for energy savings while maintaining, at all times, the minimum amount of outdoor air for occupant ventilation. This air flow tracking control strategy adds cost and complexity that is fine for large systems but is usually compromised in smaller systems because of the cost impact (see Figure 7).

Figure 7
Variable Air Volume System



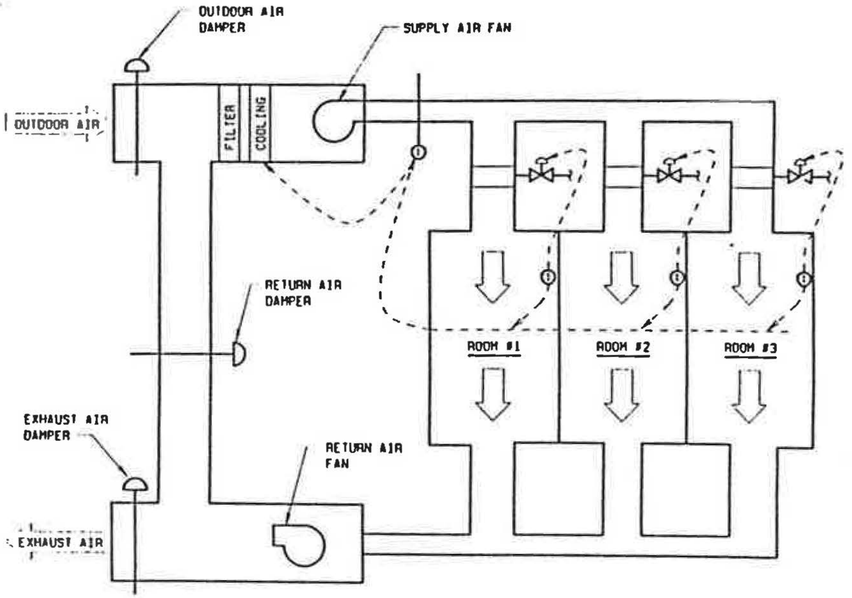
Coupled with this is the corollary that smaller systems usually do not have the associated maintenance understanding and staff that one finds in the larger systems.

An alternative design is a modified constant volume reheat system (see Figure 8). In a constant volume reheat system, the total supply air quantity is cooled and then distributed to multiple zones that each contain heating coils. These local heating coils raise the temperature of the supply air in the specific zone that is being over cooled.

This reheat system fell in disfavor with the advent of the oil embargo in the 1970s because of its wasteful concept of total cooling and, depending on the space conditions, total reheating. However, it remained advantageous for critical temperature and humidity conditions such as industrial process and medical facilities.

Since then, improved building insulation and cost effective advancements in direct digital controls allow for more accurate control of more constant building temperatures. These two factors significantly reduce the

Figure 8
Constant Volume Reset Heating Coil System



required reheat energy. Digital control reset can adjust the supply air cooling coil discharge to a higher level condition to minimize reheat requirements.

Constant volume reheat systems employed today meet the energy code (ASHRAE Standard 90.1) by using the concept of reset. Based on the advantages of constant volume air supply and assurances of adequate outdoor air intake, a constant volume reheat system is a viable alternative to variable air volume systems, and, with built-in reset, does not adversely impact operating costs.

Filtering Systems

Because 100 percent outdoor air ventilation is not cost effective, almost every HVAC system recirculates a portion of the supply air. Proper air filtering removes many contaminants, making the return air fit for reuse.

In most areas today, outdoor air also contains a number of contaminants and also requires a level of filtering depending on the surrounding building environment.

In most cases, air filters should be located after the outdoor air/return air mixing box and before HVAC equipment. In this location, filters remove contaminants in the air and also prevent contaminants from accumulating in the equipment.

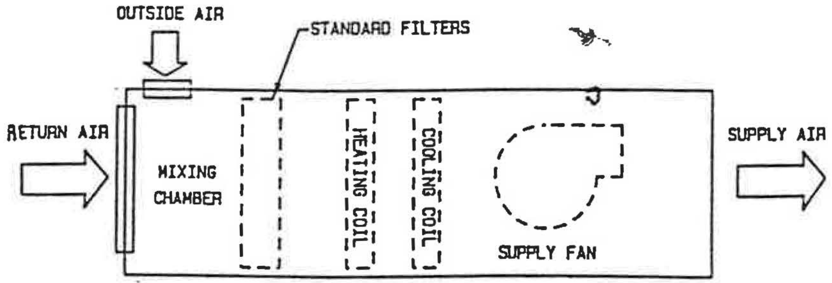
While filters act to reduce air contaminants, they can also be contaminant producers. When exposed to cool, damp air, filters can become a source of microbial growth.

Microbes feed on dirt, which accumulates within the filter over time. The accumulation of dirt restricts the air path within the filter and actually increases filter efficiency. However, the increasing air restriction causes an increased pressure drop across the filter, resulting in more energy expended to push air past the filter. Filter replacement schedules are based commonly on the economic consideration of when the operating costs associated with an increased pressure drop approach the cost of a new filter. For effective indoor air quality control based on reducing the level of dirt and microbe accumulation in a filter, and not solely on the system operating costs, filters should be replaced more frequently.

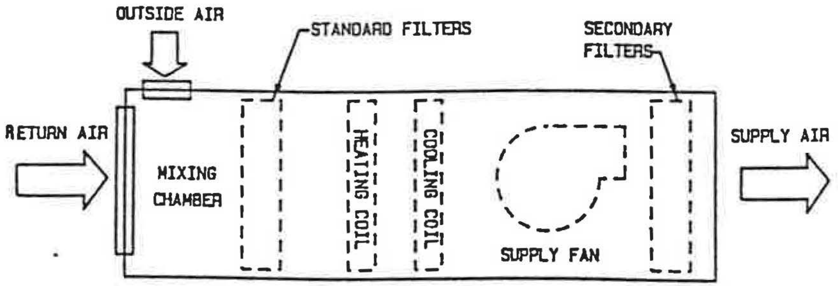
Filtration downstream of equipment may be required to accommodate ultra-low particulate demands in hospitals, laboratories, and manufacturing clean rooms. However, filters downstream of coiling coils and fans are exposed to cool, moist air. Even the most anti-fungal fiber glass filters are at risk of growing biological contaminants. In this configuration, highly consistent filter maintenance including cleaning and replacement is vital to maintaining air quality (see Figure 9).

High Efficiency Particulate Air (HEPA) filters, with particulate removal efficiencies of 99.97 percent to 99.99 percent, are useful in removal of air particulates such as smoke, atmospheric dust, and microbes. However gaseous contaminants such as volatile organic compounds and odors require adsorption filtration by activated carbon filters or other means. While advantageous for this purpose, the use of carbon filters is not

Figure 9



Standard Air Handling Unit



Air Handling Unit with Secondary Filters Downstream of Equipment
(Secondary Filters Exposed to Cold Damp Air)

permitted in many municipalities because of their lack of adequate fire resistance. An emerging technology is the use of ozone in removing VOCs and other indoor air pollutants.

Duct Silencers

The use of internal acoustic duct lining to reduce equipment noise can be a major contributor to indoor air quality problems.

Duct lining is typically installed in the ductwork near air conditioning units, variable air volume units, return fans, and in transfer ducts to help prevent the transmission of noise.

The duct lining material, although chemically treated and coated, can break down over time because of general degradation and turbulent air flow, as well as damage during initial installation. Lining damage can introduce particulates into the air. In addition, the lining surface area, exposed to damp, cool air, can become a source of microbial growth, especially in the damaged areas that provide breeding cavities.

Cleaning of lined ducts is highly unsuccessful. In most cases, cleaning with vacuum hoses serves to further disrupt the lining surface. Because the linings are usually permanently fixed to the duct surface, replacement of damaged lining requires replacement of the entire duct section.

An excellent alternative to duct lining is the use of duct sound traps or duct silencers. The two basic types of silencers are "packed" and "packless."

In packed silencers, perforated metal baffles are filled with acoustic material, which performs sound absorption in addition to sound attenuation performed by the tuning effect of the perforated baffle structures.

Packless silencers do not contain fill material. The non-perforated baffles work on the tuning principle only to attenuate sound. Packless duct silencers maintain the highest indoor air quality. Because they do not contain any fiber fill material, there is no chance for particulate generation or microbial growth in the vulnerable duct sections downstream of cooling coils and fans.

Humidification Systems

Adequate indoor air quality requires that indoor air humidity be held between about 30 percent and 70 percent relative humidity. Lower or higher levels promote microbial growth, occupant discomfort, etc. Standard air conditioning inherently results in relative humidities below 70 percent. However, in cold climates where building heating results in very low humidity levels, indoor air humidification is required to maintain relative humidity above 30 percent.

Several types of humidification systems are available, and all have varying affects on the quality of indoor air (see Figure 10).

While atomizing systems may be energy-efficient, their use can significantly contribute to indoor air quality problems. An atomizing system injects a fine spray of water into the air stream. The spray generates tiny water droplets that sometimes do not fully evaporate and can fall on duct surfaces, promoting microbial growth.

In an evaporative pan-type humidification system, no water spray is introduced into the air stream. However, this type of unit includes an internal water pan over which ventilation air passes. Stagnant water in the pan results in mineral and dirt deposits and can promote microbial growth. These contaminants are then introduced into the ventilation air passing through the evaporative humidifier.

Steam humidification systems, which inject moisture into the air stream in a vapor form, are preferable. The water vapor does not support microbial growth.

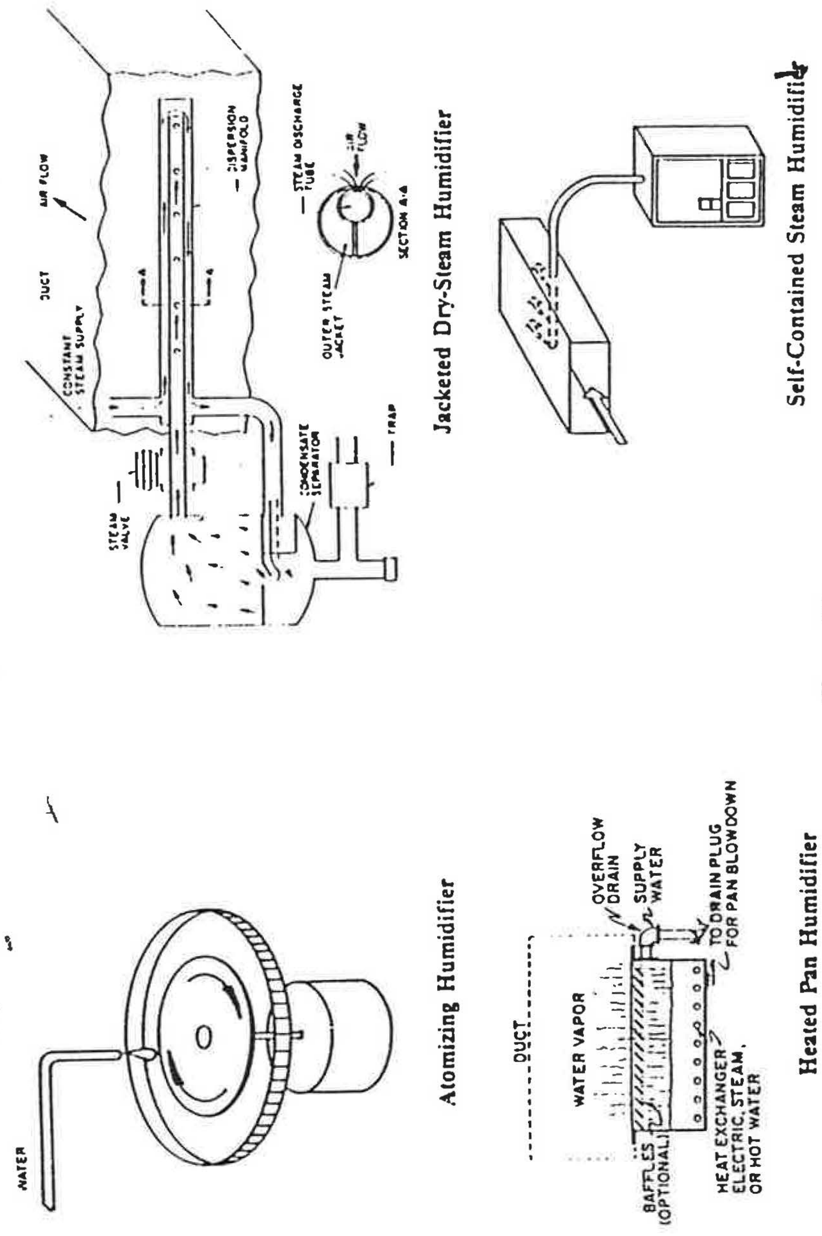
One type, a central steam humidification system, makes use of a building's boiler steam. Although energy-efficient, boiler steam may contain oil, gas, and other residue contaminants. In addition, boiler steam may contain chemical treatments that can introduce harmful contaminants into the humidifying steam.

An electric steam generating humidifier best supports high quality indoor air. The electric unit boils tap water to create steam. The steam is then injected into the air stream. The resulting steam contains minimal contaminants, and the vapor supports no microbial growth.

Although energy intensive, the electric system provides the most sanitary operation. An alternative to an electric steam generating humidifier is to supply boiler steam to a heat exchanger that, in turn, boils off a separate source of pure water for humidification.

Room Air Distribution

Room air distribution provides both fresh air renewal and contaminant removal in a space. The most effective means of room air distribution



Jacketed Dry-Steam Humidifier

Self-Contained Steam Humidifier

Atomizing Humidifier

Heated Pan Humidifier

Figure 10
(Source: 1988 ASHRAE Handbook-Equipment)

is displacement distribution or once-through flow of ventilation air through a space (see Figure 11). For example, ventilation air enters a room at the floor and room air exits at the ceiling.

Displacement offers the highest removal rate of room air contaminants. Thus, it is often the method of choice for hospitals and clean rooms.

Floor plenums can be used to distribute air to floor outlets for room supply. In addition, special carpeting is available that permits airflow through carpeted floor grates.

While displacement distribution offers the highest air quality, it is also the most costly system to operate. The high air-exchange rate demands more energy to condition and to transport the air, and zoning is more difficult.

The most common room air distribution system is overhead mixing. In this system, ventilation air enters at the ceiling, and room air also exits at the ceiling.

Overhead mixing blends ventilation air with room air, continuously exhausting a portion of the mixed air. In this way, room air contaminants are diluted and eventually removed.

The air-exchange rate is less for overhead mixing systems than for displacement systems. Overhead mixing systems commonly use only about one-third the volume of air as displacement systems. This results in less energy for air transport and conditioning. In addition, overhead mix supply air is usually maintained at about 10°F less than the temperature of displacement system supply air.

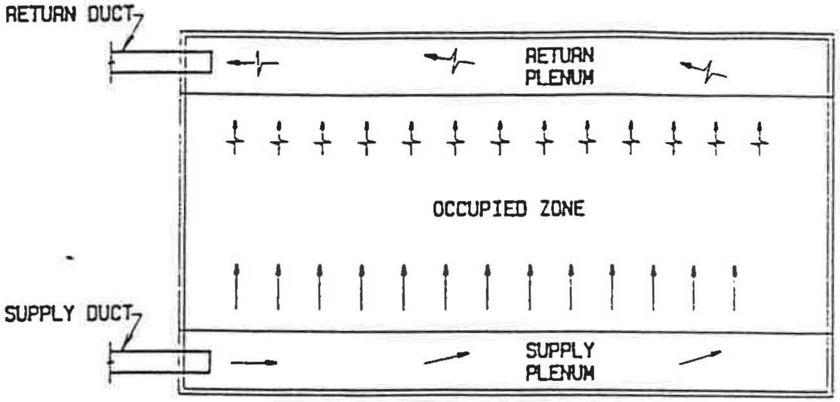
Room air distribution systems that often fall short in maintaining adequate indoor air quality include induction and fan coil units. Both designs consist of cooling/heating coils, air filters, and associated coil drain pans. The drain pans and air filters can promote significant microbial growth if not frequently maintained.

Drain Pan Design

The design of drain pans for cooling coils must provide for total water removal because stagnant water remaining in a drain pan quickly promotes microbial growth.

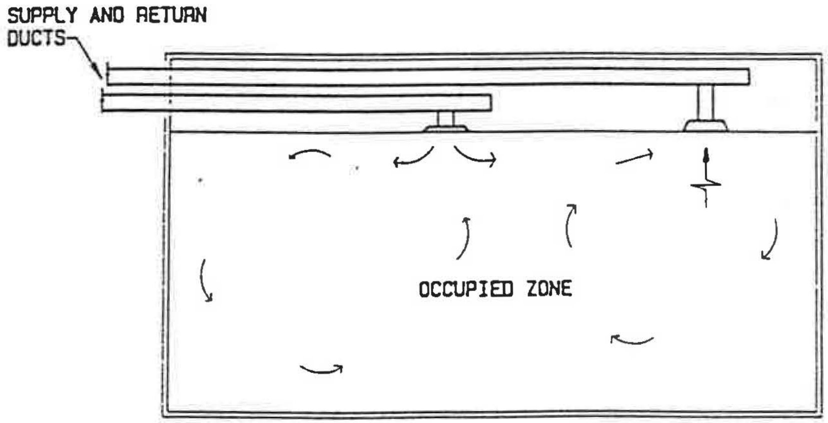
Drain pan and condensate trap design parameters include air system static pressure, trap height, pipe sizing, proper pitching of drain pans, and

Figure 11



Room Air Distribution System—Displacement

(Contaminants Removed Directly via Displacement Process)



Room Air Distribution System—Overhead Mixing

(Contaminants Removed via Dilution Process.
Note Possible Short Circuiting of Supply Air)

capacity of the equipment. Some considerations include, for example, that drain "U"-trap heights be greater than fan static pressures. Blow-through fan units create positive air pressure at the drain pan outlet and pan drainage is usually not a problem (see Figure 12). Draw-through equipment traps must be designed with enough height between the equipment drain pan and floor drain to accommodate the minimum trap dimensions required to assure proper pan drainage. This may require installing the equipment at elevated heights (see Figure 13). Also, the diameter of a drain pipe should not be less than the diameter of the drain pan connection.

Figure 12
Blow Through Unit Condensate Trap

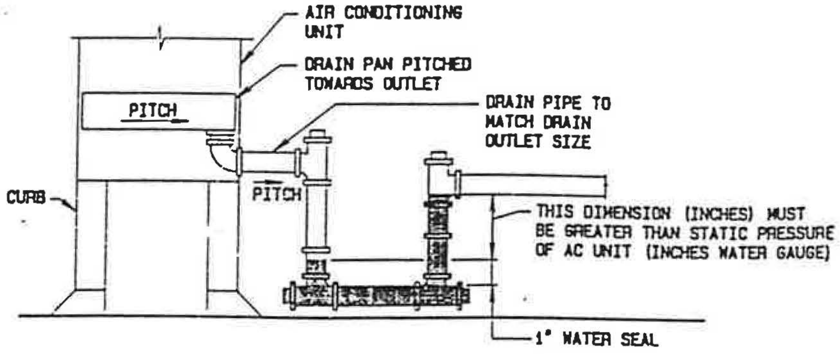
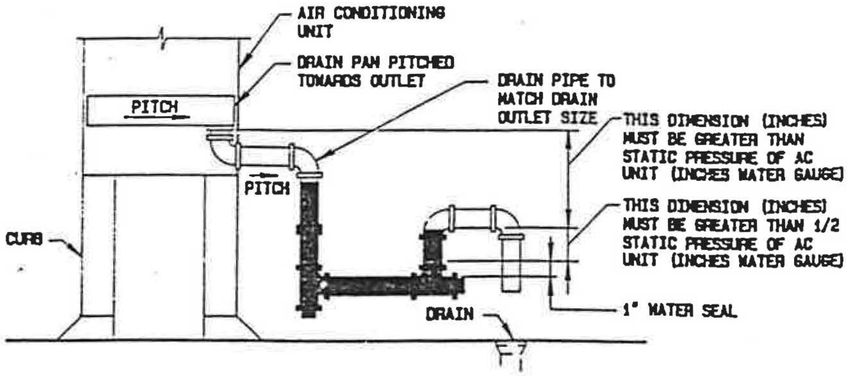


Figure 13
Draw Through Unit Condensate Trap



A condensate trap should provide an adequate water seal to prevent air at atmospheric pressure from entering the trap and impeding drainage at a lower pressure.

Properly designed drain pans and condensate traps eliminate stagnant water, thus eliminating microbial growth and its contamination of indoor air. In addition, proper designs will avoid significant maintenance and equipment downtime costs.

Planning Ahead

To achieve expected air quality performance levels throughout the life of a building, an HVAC design must be adaptable to a building's air quality needs. For example, planning ahead for future building renovations, painting, furnishing and equipment installations.

Renovation of occupied buildings poses a significant threat to indoor air quality, introducing dust from plaster, fiber glass, etc., and many types of VOCs into the air.

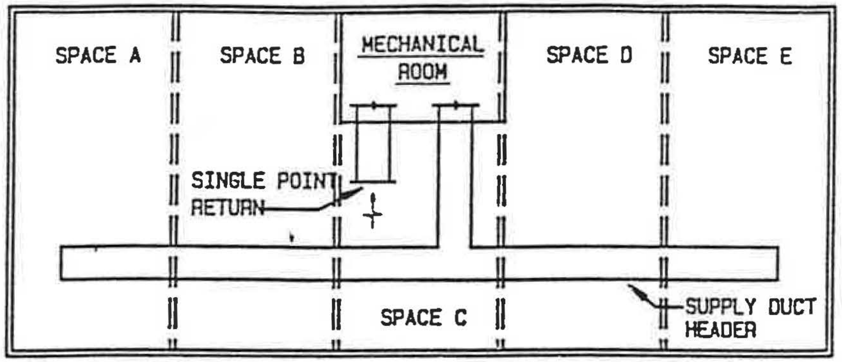
However, a properly zoned duct distribution design can effectively cut off the zone under renovation and protect the rest of the building from ventilation contaminants (see Figure 14). In addition, duct zoning combined with purge capability can quickly eliminate contaminants, such as after construction work, interior painting, or a fire.

When selecting furnishings and carpeting, as well as building materials, duct sealants and insulation adhesives, it is important to consider the level of VOC contamination the products will contribute to indoor air. Many manufacturers now test and label products with VOC off-gassing rates. VOC contamination can be subtle. For example, while a carpet product may claim very low VOC contamination rates, the adhesive with which the carpet is applied may pose a great VOC problem.

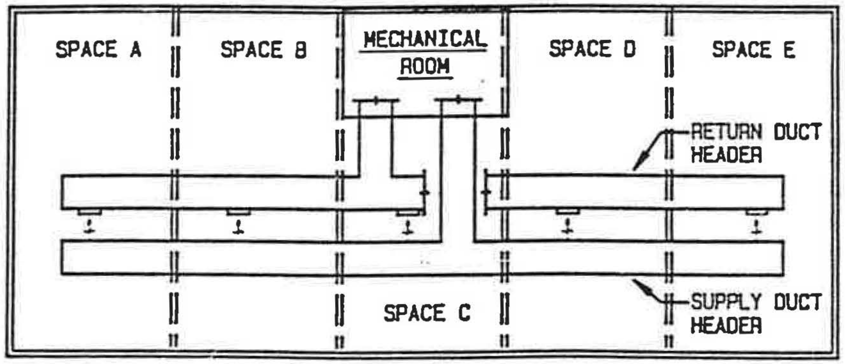
Steps can be taken to lessen the VOC contamination from furnishings. These include allowing several weeks of furniture storage for VOC off-gassing before the products are installed. For the first few weeks of building occupation, daily purges with 100 percent outdoor air can significantly improve the indoor air quality.

Office and hospital equipment can be a major contributor of VOCs and particulate contaminants. For example: carbon particulates from copy machines; ammonia odors from blue print machines; and VOCs from film developers. In addition, the equipment produces heat that affects the space cooling load.

Figure 14



Typical Plenum Return System with Single Point Return—
Requires Return Air to Transfer across Spaces via Ceiling Plenum



Typical Plenum Return System with Distributed Return—
Eliminates Transfer across Spaces and Allows for Isolation of
Spaces under Construction

A ventilation design should consider the equipment to be installed within the space and, where possible, include dedicated exhausts that will directly remove the contaminants.

The most important HVAC design element is possibly the control system that will regulate building temperature and humidity. The ability to maintain acceptable limits of temperature and humidity is what is most noticeable to building occupants and what may generate the largest number of complaints.

While many air quality contaminants go unnoticed—even at harmful levels—workers quickly notice an uncomfortable room temperature or humidity level. Additionally, humidity levels outside the comfort range can cause dryness and irritation in the eyes, nose and throat, increased microbial growth, and static electricity discharge.

Conclusion

Building owners, designers, and occupants need to consider all the design measures that contribute to high indoor air quality.

Building occupants, furnishings, equipment, and ambient air pollution all contribute to surmounting indoor air quality concerns. However, these can be minimized by following HVAC design guidelines that promote high indoor air quality while maintaining reasonable energy-efficiency.

The possible liabilities and loss of business productivity because of air quality problems are too great to ignore.

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