Indoor Air Quality

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Introduction

AUDIENCE/PURPOSE/SCOPE

This Engineering Guide is directed to consulting engineers, designbuild contractors, servicing and maintenance contractors, and their personnel; people who have a working understanding of comfort air conditioning design, maintenance, and the codes regulating the Indoor Air Quality issues of today. The reader should have access to ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, since it is the base reference document for this guide. It is assumed that the reader is familiar with basic air system layout and sizing techniques which follow well-accepted industry standards.

It is not the purpose of this guide to give detailed, procedural training on exhaust hood sizing, selection, and location; exhaust, return, or supply duct layout, materials, and sizing; room air distribution basics; or ventilation quantity, sizing, and mixture calculations. The purpose of this Engineering Guide is to highlight areas of concern which have resulted from a heightening focus on the quality of indoor air. Specific problems and solutions are presented with priorities noted and practical examples given. The current ASHRAE standard is brought to bear on the IAQ approach a designer should take in order to come up with systems that install, commission, and sign off without litigation.

ACCEPTABILITY OF BUILDING ENVIRONMENTS

1 Occupants of a building are unique in their response to the building environment. They are different in their expectations, their tolerance of disappointment, and their physical and psychological response to the environment. Due to differences in age, sex, health, social, and emotional factors, one person may complain bitterly about the same conditions that are tolerated with little concern by another, and one person may become genuinely ill as a result of conditions which do not affect most people. Because of the subjective nature of building acceptability, 100% acceptability is seldom achieved. A more realistic objective is to provide an environment in which a large majority of the building occupants are satisfied.

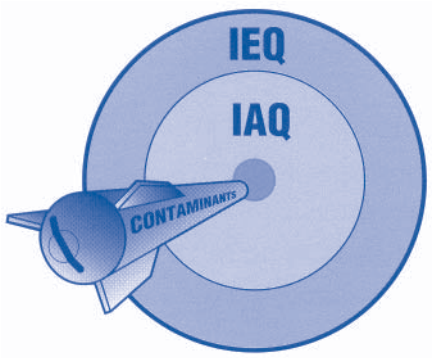
1. Indoor Environments

INDOOR ENVIRONMENTAL QUALITY (IEQ)

2 Indoor Environmental Quality (IEQ), sometimes referred to as Total Environment Quality (TEQ), is the broadest overall view of a building environment from the perspective of the occupant. It includes health, comfort, and aesthetic considerations that influence the response of the occupant to the overall environment. Superior conditions in one element may compensate somewhat for inferior conditions in another element, and vice versa. For example, poor lighting and interior room aesthetics may be more tolerable if the HVAC system controls space temperature, humidity, air motion, and cleanliness in a superior fashion. However, poor lighting and interior aesthetics may be the subject of frequent complaints if all the indoor environmental factors are of poor quality. In order to achieve good IEQ, a proper balance must be sought between all elements. Any element at its extreme worst conditions can increase stress to the body, even to the point of illness.

INDOOR AIR QUALITY (IAQ)

Indoor air quality is the appraisal of the condition of the air to which the occupant is exposed. The strict definition refers only to the presence of contaminants which may result in either an immediate or a delayed unpleasant



*2. **Indoor Environmental Quality (IAQ)***

or unhealthful response by the occupants. Recognizing the extreme sensitivity of many people, the normal definition of acceptable IAQ is that the air quality is acceptable if there are no harmful concentrations of known contaminants and if less than 20% of the occupants express dissatisfaction.

The meaning of IAQ is usually broadened to include all of the elements of comfort air conditioning, such as control of proper temperature and humidity, and sound levels. These items are relatively easy to monitor and evaluate separately, however, unlike air contaminants. This guide uses the strict definition of IAQ. However, topics such as high building humidity are discussed not because the high humidity will be uncomfortable, but because of its potential to result in the growth of harmful microbes, which will contaminate the air.

IAQ ON THE RISE

For many years air conditioning system design was considered successful if it provided adequate cooling and heating capacity with a reasonable amount of ventilation. Indoor humidity, especially at partial cooling load conditions, was assumed to be within acceptable limits, and direct control of it was reserved for critical projects. Control of airborne contaminants consisted of removing only the largest particles by use of inexpensive filters.

Today's ability to identify and measure contaminants, and the realization that many of these contaminants are harmful to a significant segment of the population, are driving the design of HVAC (heating, ventilating, and air conditioning) systems toward control of many contaminants as a design objective. Common sense tells us that a healthier building environment should result in greater worker productivity and lower health costs, making the building more attractive to tenants. The potential for litigation is another driving force. Failure to control contaminants has been construed as a major system deficiency, sufficient to prevent occupancy of the building. New building codes and HVAC design standards are demanding better system design.

It is good business to upgrade the IAQ of buildings. Buildings with good IAQ are more economical for everyone than buildings with poor IAQ. The opposite is also true. Everyone involved with an IAQ problem job is very likely to suffer.

RESPONSIBILITY FOR IAQ

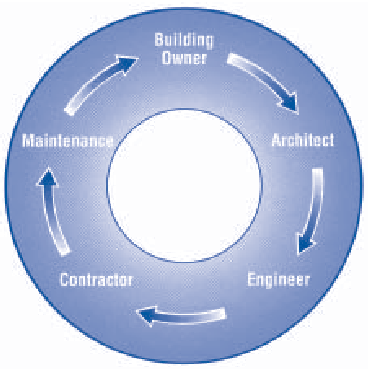
3 Since the construction or renovation of a building involves many people, the responsibility for achieving good IAQ should be assigned to all the players on the design, installation, and maintenance team, although primary responsibility lies with the building owner. The general rule is that a person becomes liable for a situation when they have a duty to perform and when they fail to perform that duty.

The architect is usually deemed responsible for the overall design of a project, including the HVAC system. The location of air inlets and outlets through exterior walls and roofs, and specifications regarding the release of chemical vapors from the many construction and finishing materials are among the many items that can be controlled by the architect. Even site selection, building orientation, and grading can influence IAQ. When an architect is not used, as is usually the case in retrofit, replacement, and some renovation work, the architect's responsibility is passed along to the one who assumes overall building design responsibilities.

The engineer providing the design of the HVAC system has a duty to design the system in accordance with construction codes and other generally accepted standards, such as *ASHRAE 62, Ventilation for Acceptable Indoor Air Quality*. The engineer has the duty to document the design of the system so that it can be constructed and operated properly, and to make this information available to the contractor and operator of the system. Assumptions on how the building is to be used and its operating schedules must be explicit.

The contractor has primary responsibility for the construction work. Contractors are particularly liable for deviations from the design and material specifications. Duties related to IAQ can include control of contaminants during construction, protection of materials and furnishings from contamination before and after they have been installed, and provision of a construction schedule which allows time for the building to be properly commissioned before occupancy.

The operator and/or owner of the system have primary responsibility for operating and maintaining the system per design intent and manufacturer's recommendations. Deviations from the intended design are their own responsibility. The operator/owner is also responsible for communicating, monitoring, and controlling the actions of the occupants/tenants and building operating staff that result in contaminants that were not intended or could not be reasonably foreseen and protected against during the design of the system.



*3. **IAQ Responsibility***

A cooperative relationship between these entities provides the greatest assurance that the final operating system will be free of major IAQ problems, and that any problems which occur will be solved without litigation. A team council comprised of the architect, engineer, contractor, owner, and operator should meet to communicate and coordinate regularly as the project is implemented.

IAQ Fundamentals

The focus of IAQ design is to control the airborne contaminants within acceptable limits at the location(s) of the occupants. This is generally accomplished by control of contaminants at their source, by eliminating the source of the contaminant itself; by a local exhaust to capture an indoor contaminant; or by dilution, such as by replacement of contaminated room air with supply air that has a much lower level of contamination. Dilution can be accomplished by filtration, gaseous treatment devices, or ventilation. This section discusses some of the basic issues that are involved in controlling the IAQ within a building.

COMMON CAUSES OF IAQ PROBLEMS

4 Following are seven categories of design and service practices that cause IAQ problems.

OCCUPANCY DURING CONSTRUCTION

Construction-related activities are responsible for a large percentage of problems. Construction generates large amounts of dust and many gaseous contaminants from paints, sealants, and adhesives. Outgassing from new carpet, furniture, fabrics, and wall coverings can require greatly increased ventilation for proper dilution of fumes for several weeks or months.

With new buildings, occupancy of the building before construction is completed and before the HVAC systems have been properly commissioned is especially hazardous.

With existing buildings, the greatest problems are failure to isolate and ventilate the spaces under renovation, and failure to maintain them at a negative pressure with respect to surrounding areas until their pollutants are reduced to acceptable levels. Temporary exhaust fans are usually most effective in maintaining negative pressure in the renovation area. Where common supply air systems serve both occupied spaces and

1. **Occupancy of the Building During Construction Activity**
2. **Inadequate Filtration**
3. **Improper Building Operation or Maintenance**
4. **Inadequate Moisture Control in Climates with High Outdoor Humidity**
5. **Failure to Design for Actual Space Usage**
6. **Poor Outdoor Air Quality at the Ventilation Intake**
7. **Insufficient Ventilation from a Central Air System Serving Diverse Areas**

4. Common Sources of IAQ Problems

spaces under renovation, fire dampers can be closed, or blankoffs can be installed at return grilles, or in ductwork, to prevent the flow of contaminated return air from the renovation area into the system and, consequently, to the rest of the building.

The practice of using inexpensive and ineffective low-efficiency “construction filters” while air handling equipment is operated during the late stages of construction is especially damaging. Operation of the equipment without adequate filtration will result in contamination of the air handling equipment and the entire air distribution system. It is recommended that HVAC equipment not be operated or else high-efficiency filters be used during this time.

INADEQUATE FILTRATION

Filters are often selected based on minimum code and cost standards. Low-cost media filters fail to remove particulate contaminants from the room and permit them to enter the space from outdoors. High-quality filters contribute significantly to indoor air quality by removing mold and mildew spores, bacteria, pollen, and even viruses. The benefit of higher efficiency media can be lost if multiple filter installations do not seal tightly along their frames. Bypassed air is unfiltered air.

BUILDING OPERATION AND MAINTENANCE

Improper building operation and maintenance is a major cause of IAQ problems. Use of dangerous volatile compounds for cleaning operations, storage of such compounds in air handling equipment rooms and return air plenums, inadequate pest control, and failure to identify tenant-related activities which generate unexpected contaminants are common occurrences. Failure to operate the HVAC systems as intended, or intentionally disabling ventilation dampers or controls to reduce energy consumption often becomes less prevalent as the importance of IAQ is recognized. The HVAC designer or contractor can help to ensure proper system operation by providing adequate information in a timely and understandable manner. The designer and/or contractor may be held liable for improper operation if they fail to provide adequate documentation.

MOISTURE CONTROL

Inadequate control of moisture is the major IAQ problem in humid climates. Where air is exhausted, fresh, outdoor makeup air must take its place. Failure to pressurize the building with adequate makeup air results in infiltration of high humidity outdoor air through the building skin. The choice of systems with poor humidity control characteristics at partial cooling loads and construction of the building exterior skin with inadequate protection against water and vapor leakage are the frequent mistakes.

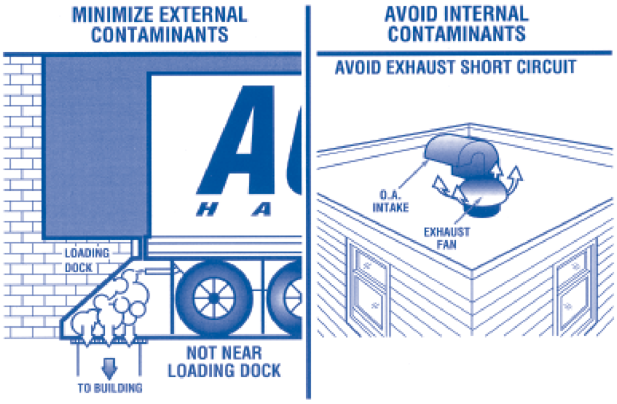
USAGE OF SPACE

Failure to properly identify the intended use of a space is a continuing problem, especially with rental buildings and renovation projects where the original HVAC system type or design may be inadequate for the actual usage of the space. Speculative buildings make usage hard to nail down. A compromise must be sought between system IAQ flexibility and first cost. In a speculative situation without IAQ flexibility, the system is destined to become an IAQ problem.

VENTILATION CONTAMINANTS

5 Unexpected contaminants at the ventilation air intakes may create an air quality problem. The ventilation air may be contaminated by engine fumes if the intake is close to loading docks, electric power generators, highways, or garages. It can also be contaminated by air discharged from nearby exhaust fans, cooling towers, and boiler or incinerator flues.

Example: ***Air taken through an intake near a truck loading dock is different than air taken at the 20th floor level. Air near the boiler or incinerator stack on the roof is different from air taken through the top floor building wall. Since the airflow patterns from contaminant sources depend upon many factors, such as the wind velocity and direction, the contaminant discharge velocity and direction, and the shape of nearby building walls, it is not***



5. Locate Outdoor Air Intakes Wisely

practical to recommend minimum distances between ventilation intakes and contaminant sources. The designer should focus on separating these elements to the greatest practical degree.

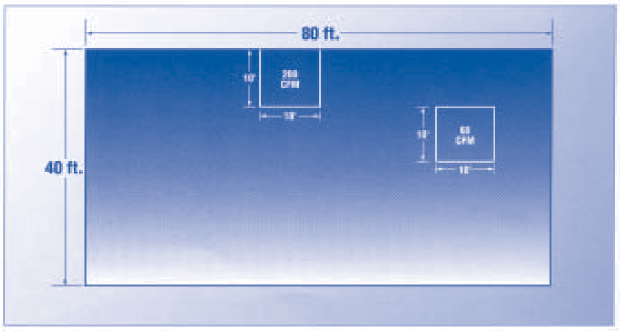
INSUFFICIENT CENTRAL VENTILATION

Ventilation is an important determiner of IAQ because outdoor air is used to dilute indoor contaminants to a reasonable level and to replenish oxygen consumed in the space.

Insufficient ventilation airflow was not identified as a problem in most buildings built before about 1970. The typical building had operable windows with considerable infiltration. Because energy was relatively inexpensive, there was little incentive to minimize ventilation rates.

During the next two decades, rising energy costs and energy conservation measures, such as improved insulation, fixed glass, and sealant systems resulted in less ventilation and infiltration. At the same time, greater use of building materials and furnishings with adverse chemical releases created a greater need for dilution of chemical vapors. This combination of less ventilation and more chemical releases resulted in many situations with obvious IAQ problems. Beginning about 1990, awareness of the importance of ventilation and the publicity regarding many buildings with IAQ problems resulted in better designs. Most buildings are now designed with ventilation rates that will be adequate as long as the system is operated in accordance with design intent. In most cases, design ventilation rates will provide adequate dilution, as long as other conditions, which cause excess building contamination, are avoided. While ventilation is necessary and dilution with outdoor air can be an effective measure for achieving satisfactory IAQ, it is not a cure-all for IAQ problems. All the items in Figure 4 must be considered.

6 Inadequate ventilation occurs on central air systems when proper attention is not given to varying load and population density. With a central air system serving multiple zones, ventilation is proportional to supply airflow.

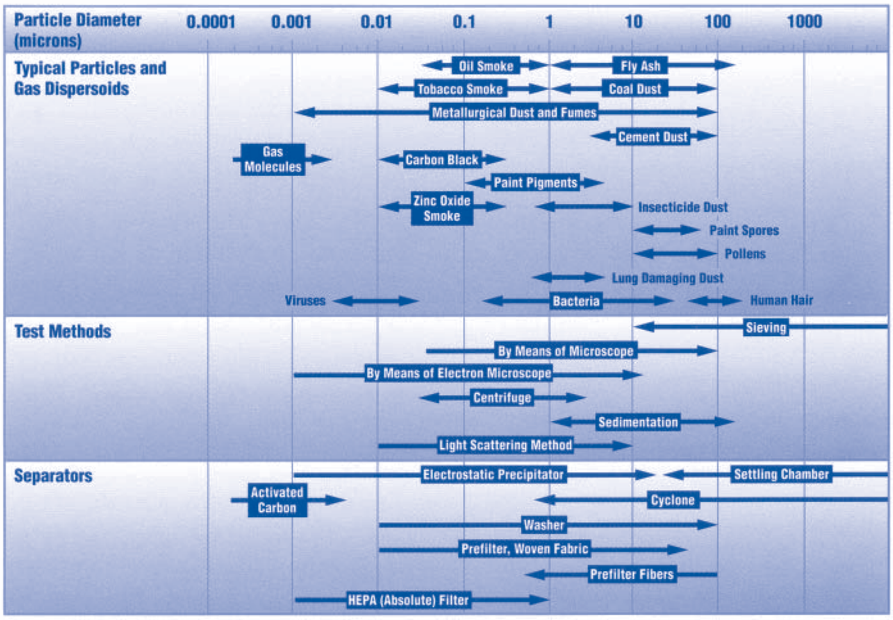


6. Ventilation is Proportional to Supply Air CFM

Example: Two, 100 sq. ft. offices with similar occupancy patterns require similar ventilation. However, due to load differences, the exterior office needs 200 CFM of supply air while the interior office requires only 60 CFM. If both of these offices are conditioned by the same central air system, the ventilation each room receives is proportional to the supply airflow. If the system provides 15% ventilation air, the exterior office will receive 30 CFM of outside air (200 CFM x .15), while the interior office receives only 9 CFM (60 CFM x .15).

If the code requirement sets the minimum ventilation at 20 CFM/person, then the ventilation rate for the interior office is inadequate. To meet code for the worst case or "critical zone," the whole system will have to provide 33% ventilation (20 CFM/60 CFM), a substantial boost over the original 15% rate. In this case, the exterior office is overventilated, receiving 66 CFM of outdoor air (330% of that needed) in order to satisfy the need of interior offices.

Some codes accept the ventilation rate if the average for the floor is adequate. In our example, an average ventilation rate of 20 CFM per person, at 100 sq. ft. per person, would mean 640 CFM per floor. The more core area there is, the higher the required outdoor air percent will be. In the example illustrated, if we assume every perimeter module needs 200 CFM of supply air and every core module needs 60 CFM, only 14% ventilation is needed. The percent is low because the example has a small core area.



7. Typical Air Contamination Particle Sizes

CONTAMINANTS AND THEIR SOURCES

7 A contaminant is defined as anything in the air that is harmful or objectionable to the building occupants, an industrial process within the building, or to the building or its contents. Contaminants can be either physical particles that are suspended in the air, or gaseous substances. Figure 7 shows the approximate sizes of many of the physical contaminant particles that may have to be removed from the air.

8 Indoor contaminants come from both indoors and outdoors. Figure 8 lists some of the most common contaminants from each area.

Asbestos is not included in this discussion because it is unlikely to be a consideration in new construction. Where it is found in existing buildings, it should always be mitigated independently by a specialist.

Lead is not included because the level of lead compounds in atmospheric air has declined due to the use of lead-free gasoline. Lead dust, from the disturbance of lead paint during renovation of existing buildings, can be a significant hazard which must also be mitigated by a specialist.

INDOOR CONTAMINANTS

- Dust (especially dust from paper and skin particles)
- Dust Mites
- Lint, Hair, and Fibers
- Mold Spores, Bacteria, Viruses, and Other Microorganisms
- Environmental Tobacco Smoke (ETS)
- Volatile Organic Compounds (VOCs): Include most gases released from cleaning compounds, construction materials, building furnishings, copiers, printers, etc.
- Toiletries and Perfumes Worn by Occupants
- Ozone

OUTDOOR CONTAMINANTS

Airborne Dust	Local Industrial Emissions
Pollens and Mold Spores	Regional Smog and Ozone
Local Traffic Fumes	Radon

8. Contaminants from Indoors and Outdoors

CONTROL OF CONTAMINANTS

In the past, ventilation was often viewed as an adequate answer to controlling contaminants generated within the building. However, the treatment of outdoor air is too costly to follow this simplistic strategy today, and it fails to fully address the issue of contaminants brought in from outdoors. In many areas, outdoor air moisture aggravates microbial growth indoors. In addition, many urban and suburban areas have worse outdoor air than the design standards set for the indoor environment. Therefore, a proper contaminant control strategy should be viewed as a three-step process.

SOURCE CONTROL

9 The first step is to minimize the generation of contaminants within the space, by controlling the activities within the space (Figure 9). Prevent moist and dirty environments which are conducive to the growth of microorganisms. Ceilings and building furnishings which have been exposed to water leakage should be cleaned or replaced. Activities such as workshops, where large amounts of dust and volatile contaminants are released, can usually be provided for by separate HVAC systems in separate areas of the building.

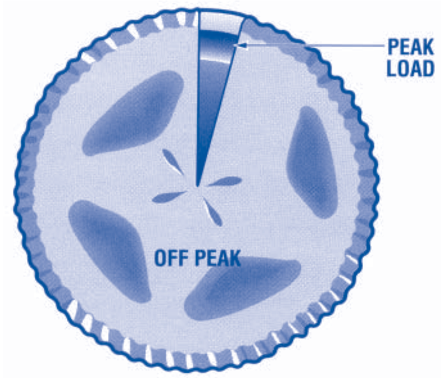
The growth of microorganisms is promoted by dust, moisture, and warm temperatures. It is limited by lack of food or water. Humidity below 60% can limit the water supply. Dirty, standing water is very likely to result in dangerous microorganism growth.

Example: A room fan coil unit is equipped with a poorly fitting lint filter and is improperly leveled so that the drain pan pitches away from the drain connection. Bacteria growth is likely.

1. **SOURCE CONTROL**
   - Minimize Generation
   - Prevent Hazardous Growth
   - Isolate Contaminant Areas
   - Provide Part-Load Humidity Control
   - Exhaust Locally
2. **FILTRATION AND/OR GASEOUS TREATMENT**
   - Mechanical (Filtration)
   - Particulate Removal (Filtration)
   - Chemical (Gaseous Treatment Device)
   - Gas Removal (Gaseous Treatment Device)
3. **DILUTION**
   - Adequate Minimum Outside Air
   - Demand-Based Ventilation (CO_2 Sensing)

9. Priorities for Contaminant Control

10 HVAC systems vary greatly in their moisture removal capacity, especially when the room sensible cooling load is less than "design load" conditions, and the system is operated by a thermostat, which controls dry bulb temperature.



10. "Off-Peak" is Where We Live

11 The system design is usually focused on "design load" conditions, in order to determine the necessary peak capacity of equipment and distribution systems. Recognizing that systems seldom operate at these peak design loads, it may be necessary to evaluate the humidity control performance of the proposed system at the partial loads which create the biggest humidity problems. A building with high relative humidity for long periods is very likely to have significant microbiological contamination.

Example: An office area must be designed with enough capacity to handle large loads which occur during the normal daytime period, but must be operated during nights and weekends to serve greatly reduced occupancy and structure heat gains. Figure 9 shows that an indoor humidity of about 70% RH will probably occur if the system uses a constant-volume air handling unit with a modulating chilled water valve controlled by a room thermostat.

The two columns of data demonstrate that as the chilled water valve modulates toward its closed position, the coil latent capacity is reduced much more rapidly than its sensible capacity. Even though the latent cooling load from both the space and outdoor air are greatly reduced, the space relative humidity is quite high. This happens because reduced water flow raises the cooling coil dewpoint temperature.

TYPICAL CONSTANT VOLUME SYSTEM
DRAW-THRU AIR HANDLING UNIT WITH MODULATING CHILLED WATER COIL VALVE

Load Condition	Design Load, Sunny Day	Part-Load, Night
Occupancy	100%	20%
Outdoor Air Condition	95 DB, 76 WB	80 DB, 71 WB
Room Sensible Heat	270,000	100,000
Room Latent Heat	25,000	5,000
Safety Factor	27,000	0
Outdoor Air Sensible Heat	43,200	10,800
Fan Heat Gain	90,000	90,000
Outdoor Air Latent Heat	57,100	9,200
Supply Air CFM	15,000	15,000
Cooling Coil Dewpoint	53.5°F	65.5°F
Room Conditions	*75 DB 48% RH*	*75 DB 71% RH*

11. Humidity Buildup at Part Load

Better humidity control can be provided by changing the system and control so that the room thermostat modulates airflow through or around the chilled water coil, using a face and bypass damper, instead of modulating the chilled water flow through the coil. Other alternatives with better part-load humidity performance include variable air volume and reheat control. Reheat controls are banned by some building codes because of their energy penalty. However, condenser reheat coils and various heat reclaim applications often permit reheat without serious energy compromise. Sorbentdehumidification by the use of dessicant wheels or other devices is a chemical alternative in humidity removal.

Local Exhausts

Another way to control contaminants at their source is to isolate and remove as many locally generated contaminants as possible, using hoods and exhausts. This works best when a pollutant is generated by a process that is contained in a small area. Minimizing the spread of local contaminants into the general building area greatly simplifies the cost and difficulty of conditioning the entire building.

THE DILUTION PROCESS

The second and third steps (Figure 9) prevent contaminant levels from rising above acceptable levels in the occupied spaces of the building by using a dilution process. Dilution is accomplished by a combination of air filtration, chemical air treatment using a gaseous treatment device, and outdoor air ventilation. This is simple in concept, but greatly complicated by the existence of hundreds of potential contaminants with a different acceptable concentration level for each c ontaminant.

Air Filters

ASHRAE Standard 52 addresses the performance of air filters and the rating methods which are used to develop performance ratings. Standard 52.2P, a proposed revision of this standard, classifies particulate filters by efficiency as either ultra high, high, medium, low, or coarse, with several sub-grades of each broad category. These classifications are used in the following discussion. Other performance characteristics, such as dust capture rates, dust holding capacities, and air pressure drops, are also necessary to define the effectiveness of a filter.

Most commercial buildings and hospitals can be served effectively with either low, medium, or high performance filters. Filters within these classifications are generally either the media-type or the high voltage electronic-type. Since the majority of filters used in commercial buildings are media-type filters, the remainder of this discussion is directed to these filters.

The choice of filter is obviously related to the type and size of particle which is to be removed. Figure 7 showed the typical size of many particulates. From this chart, it is seen that most pollens and dust particles are relatively large, above 5 or 10 microns in size. Most bacteria and some dust particles are smaller, down to about 0.5 micron or less, while viruses are about 0.01 micron.

To be continued