Building Air Quality

A Guide for Building Owners and Facility Managers

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Atmospheric and Indoor Air Programs
Indoor Air Division

U.S. Department of Health and Human Services
Public Health Service
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DISCLAIMER

This document has been reviewed in accordance with policies at the U.S. Environmental Protection Agency and the National Institute for Occupational Safety and Health. Information provided is based upon current scientific and technical understanding of the issues presented. Following the advice given will not necessarily provide complete protection in all situations or against all health hazards that may be caused by indoor air pollution. Mention of any trade names or commercial products does not constitute endorsement or recommendation for use.

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Foreword

In the past two decades, the number of people requesting information and assistance on health and comfort concerns related to indoor air quality from the U.S. Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) has risen steadily. Although many studies on indoor air quality have been reported in technical publications and proceedings during these years, little indoor air-related information has been targeted at owners and facility managers of public and commercial buildings who are the people in the best position to prevent and resolve indoor air problems.

In recognition of the need for practical indoor air quality advice for building owners and facility managers, EPA and NIOSH decided to work jointly to produce written guidance on preventing, identifying, and correcting indoor air quality problems. The distinct perspectives of the two agencies are reflected in this document.

Since 1971, NIOSH has conducted more than 600 indoor air quality investigations in the office (non-industrial, non-residential) buildings under the Health Hazard Evaluation Program. Over time, NIOSH has developed a "solution-oriented" approach to these investigations. This document draws extensively on the experience of NIOSH in investigating and correcting indoor air quality problems in these types of buildings.

In 1986, Congress mandated that EPA conduct research and develop information on indoor air quality. To carry out its information dissemination responsibilities, EPA's Indoor Air Division has produced a number of publications which have been distributed to a wide range of audiences and will launch an indoor air quality information clearinghouse in 1992. In addition, the Indoor Air Division is developing several guidance documents on building design and management practices. This publication is part of that effort.

The guidance presented here is based on what is known and generally accepted *at this time* in the relevant fields of building science and indoor air quality. EPA and NIOSH anticipate that this document may later be revised to include more detailed guidance as research continues and our knowledge grows. In the meantime, building owners and facility managers can use the Resources section to supplement and update the information presented here.

Note to Building Owners and Facility Managers

From marketing and negotiating leases and maintenance contracts to planning for future expansion, operating a commercial or public building is a complex process that leaves you little time for unnecessary activities. Working with your facility staff, you make an effort to provide a pleasant setting and are accustomed to dealing with occupant complaints about room temperature, noise, plumbing system problems, and other elements of the building environment.

A healthy indoor environment is one in which the surroundings contribute to productivity, comfort, and a sense of health and well being. The indoor air is free from significant levels of odors, dust and contaminants and circulates to prevent stuffiness without creating drafts. Temperature and humidity are appropriate to the season and to the clothing and activity of the building occupants. There is enough light to illuminate work surfaces without creating glare and noise levels do not interfere with activities. Sanitation, drinking water, fire protection, and other factors affecting health and safety are well-planned and properly managed.

Good air quality is an important component of a healthy indoor environment. For the purposes of this document, the definition of good indoor air quality includes:

- introduction and distribution of adequate ventilation air
- control of airborne contaminants
- maintenance of acceptable temperature and relative humidity

A practical guide to indoor air quality (IAQ) cannot overlook temperature and humidity, because thermal comfort concerns underlie many complaints about "poor air quality." Furthermore, temperature and humidity are among the many factors that affect indoor contaminant levels.

It is important to remember that while occupant complaints may be related to time at work, they may not necessarily be due to the quality of the air. Other factors such as noise, lighting, ergonomic stressors (work station and task design), and job-related psychosocial stressors can — individually and in combination — contribute to the complaints. These problems are briefly addressed in this document.

Good indoor air quality enhances occupant health, comfort, and workplace productivity. Rental properties can gain a marketing advantage if they are known to offer a healthy and pleasant indoor environment. Failure to respond promptly and effectively to IAQ problems can have consequences such as:

- increasing health problems such as cough, eye irritation, headache, and allergic reactions, and, in some rare cases, resulting in life-threatening conditions (e.g., Legionnaire's disease, carbon monoxide poisoning)
- reducing productivity due to discomfort or increased absenteeism
- accelerating deterioration of furnishings and equipment
- straining relations between landlords and tenants, employers and employees
- creating negative publicity that could put rental properties at a competitive disadvantage
- opening potential liability problems (*Note:* Insurance policies tend to exclude pollution-related claims)

Provision of good air quality requires conscientious effort by both building staff and occupants. The commitment to address IAQ problems starts with the building owner or facility manager, the person who has an overview of the organization, sets policy, and assigns staff responsibilities. You have the authority to see that an IAQ policy is articulated and carried out, the ability to identify staff with skills that enable them to react promptly and effectively to complaints, and the incentive to initiate a program that will prevent indoor air problems in the future. As you decide how best to respond to the challenge of preventing and resolving indoor air quality problems in your building, it will be helpful to keep in mind the following thoughts:

It is important to establish a process that encourages an active exchange of information.

Without an open communications policy, an atmosphere of distrust may be created that complicates your efforts to diagnose and correct problems.

Facility staff are in a position to notice malfunctioning equipment or accidental events that could produce indoor air quality problems.

They can play a critical role in identifying problem situations and averting IAQ crises. On the other hand, if staff are not aware of IAQ issues, their activities can also create indoor air quality problems.

Facility staff are often instructed to keep energy costs to a minimum.

Changes in building operation intended to save energy have sometimes contributed to IAQ problems (for example, by reducing the flow of outdoor ventilation air without taking action to maintain the quality of the recirculated air). The correction of IAQ problems has sometimes led to reduced energy use due to the efficiency associated with a cleaner, and better controlled heating, ventilation, and air conditioning (HVAC) system. The energy needed to condition and distribute ventilation air is only a small part of total building energy consumption and is far overshadowed by other operating costs (such as personnel). Attempting to limit operating costs by reducing ventilation can be a false economy, if it leads to problems such as increased occupant complaints, reduced productivity, and absenteeism.

Every complaint merits a response.

Many indoor air quality problems are not difficult to correct and can be solved with in-house expertise. However, gathering relevant information about the problem and identifying appropriate corrective actions is likely to require a coordinated effort by people with a variety of skills.

An indoor air quality problem may be the direct or indirect result of an apparently minor modification.

Actions such as the placement of interior room dividers, the introduction of new office equipment, and personal activities such as cooking can have an impact on indoor air quality. Communication between building management and building occupants regarding their respective responsibilities is a critical element in the management of indoor air quality.

Indoor air quality in a large building is the product of multiple influences, and attempts to bring problems under control do not always produce the expected result.

Some indoor air quality problems are complex and may require the assistance of outside professionals. When contracting for services, you need to be an informed client to avoid unnecessary costs and delays in solving the problem.

If there is reason to believe that an IAQ problem may have serious health implications, appropriate experts such as occupational physicians, industrial hygienists, and mechanical engineers should be called in as soon as possible.

In-house investigations by non-professionals are not recommended in such cases (e.g., if individuals are being hospitalized because of exposure inside the building).

Public and commercial buildings can present a wide range of IAQ problems.

The variety of unique features in their design and usage (e.g., apartment buildings, hospitals, schools, shopping malls) make a wide range of IAQ problems possible. In apartment buildings, for example, each residential unit can produce cooking odors and the operation of kitchen exhaust fans is generally outside the control of building management. The basic information and problem-solving processes in this guide can be applied, with necessary adaptations, to a wide range of building types.

This document was written to be a useful resource for you and your staff in preventing and resolving occupants' complaints that may be related in some way to the quality of the indoor air. It provides background information followed by "how-to" guidance for you and your in-house staff. The practical problem-solving techniques it describes have been applied successfully by NIOSH and other investigators. If complaints are not resolved after careful application of this guidance, outside help will probably be needed. Information on possible sources of outside help is included. As you read this document, or turn it over to your staff to implement, EPA and NIOSH urge you to maintain a personal involvement in this issue.

SELECTED INDOOR AIR QUALITY PROBLEMS

This box is provided to help building owners and facility managers get acquainted with examples of IAQ problem indicators and associated responses. Some IAQ problem situations require immediate action. Other problems are less urgent, but all merit a response.

Problems Requiring Immediate Action	**There have been complaints of headaches, nausea, and combustion odors.**	Carbon monoxide poisoning is a possibility. Investigate sources of combustion gases right away.
	One or more occupants of your building have been diagnosed as having Legionnaire's disease.	This is a potentially life-threatening illness. Request Health Department assistance in determining whether your building may be the source of the infection.
	Staff report that water from a roof leak has flooded a portion of the carpeting.	If damp carpeting cannot be lifted and thoroughly dried within a short time, it might need to be discarded. Proper cleaning and disinfection procedures must be used to prevent the growth of mold and bacteria that could cause serious indoor air quality problems.
Problems That Require A Response, But Are Not Emergencies	**Inspection of the humidification system reveals an accumulation of slime and mold. There have been no health complaints suggesting IAQ problems.**	Inadequately maintained humidifiers can promote the growth of biological contaminants. Clean equipment thoroughly, and consider modifying maintenance practices.
	A group of occupants has discovered that they share common symptoms of headaches, eye irritation, and respiratory complaints and decided that their problems are due to conditions in the building.	The symptoms described suggest an IAQ problem that is not life-threatening, but it would be wise to respond promptly.
	Immediately after delivery of new furnishings (furniture or carpeting), occupants complain of odors and discomfort.	Volatile compounds emitted by the new furnishings could be causing the complaints.
	Local news articles suggest that some buildings in the area have high indoor radon levels.	The only way to determine the indoor radon concentration in a given structure is to test in appropriate locations.
	You wonder whether some old pipe insulation contains asbestos.	Asbestos can be positively identified only by laboratory analysis.

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BASICS

Building Air Quality

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About This Document

1

BEFORE YOU BEGIN

The goal of this guidance document is to help you prevent indoor air quality problems in your building and resolve such problems promptly if they do arise. It recommends practical actions that can be carried out by facility staff, outside contractors, or both. The document will help you to integrate IAQ-related activities into your existing organization and identify which of your staff have the necessary skills to carry out those activities.

This is a long document. It would be convenient if all of the ideas it contains could be summed up in a few short recommendations, such as: "check for underventilation" and "isolate pollutant sources." However, such statements would only be helpful to people who are already familiar with indoor air quality concerns. If the owner's manual for your car said to check your pollution control valves every year, but didn't say how to find out whether they were working properly, you would need either a more detailed manual or the money to hire a mechanic. Don't be discouraged by the number of pages in your hands. Once you begin to understand the factors that influence indoor air quality in your building, you can move from section to section, reading what you need to know at the moment and leaving the rest until later.

Some Basic Assumptions

EPA and NIOSH recognize that many factors influence how an individual owner or manager can put the information in this guide to use. The skills of facility staff and the uses of the building can vary widely, affecting the types of IAQ problems that are likely to arise and the most effective approach to resolving those problems.

The assumptions used in preparing this guide include:

- The expense and effort required to prevent most IAQ problems is much less than the expense and effort required to resolve problems after they develop.
- Many IAQ problems can be prevented by educating facility management, staff, and occupants about the factors that create such problems. When IAQ problems do arise, they can often be resolved using skills that are available in-house.
- The basic issues and activities involved in preventing and resolving IAQ problems are similar for buildings of many different designs and uses.
- If outside assistance is needed to solve an IAQ problem, the best results will be achieved if building owners and managers are informed consumers.

How this Guide is Organized

This guide is divided into topic areas marked by tabs. **Tab I** marks introductory material directed toward all users of the document. **Tab II** is directed to building owners and facility managers who do not have a current IAQ problem and want to prevent such problems from arising. If you currently have an indoor air quality problem, **Tab III** provides guidance to help resolve that problem. The appendices marked by **Tab IV** present information that may not be critical to resolving most indoor air quality problems but could be useful reading for additional background on major IAQ topics. Abbreviated sample forms are included throughout the text so that readers can see what types of information can be collected using the forms provided in this document. **Tab V** contains the complete forms discussed in the text. These can be photocopied for use by you and your staff.

As you read this document, you will find that some guidance points are repeated. This was intentional, as it allows you to use the sections on prevention, diagnosis, and mitigation as "stand-alone" guides.

Tab I: Basics

Section 2: Factors Affecting Indoor Air Quality

Indoor air quality is not a simple, easily defined concept like a desk or a leaky faucet. It is a constantly changing interaction of a complex set of factors. Four of the most important elements involved in the development of indoor air quality problems are: a source of odors or contaminants; a problem with the design or operation of the HVAC system; a pathway between the source and the location of the complaint; and the building occupants.

Read *Section 2* for an introduction to the factors that influence indoor air quality. A basic understanding of these factors is critical to investigating and resolving IAQ problems.

Section 3: Effective Communication

An effective communication system helps facility managers, staff, contractors, and occupants to clarify their responsibilities and cooperate in identifying potential IAQ problems. Building occupants can be valuable allies in resolving indoor air quality problems. On the other hand, even small problems can have disruptive and potentially costly consequences if occupants become frustrated and mistrustful. Effective communications are the key to cooperative problem-solving.

Good communications can be promoted through a group that represents all of the interested parties in the building. Many organizations have health and safety committees that can fill this role. *Section 3* suggests ways to work productively with building occupants to prevent IAQ problems and to maintain good communications during IAQ investigations.

Tab II: Preventing IAQ Problems

Section 4: Developing an IAQ Profile

An IAQ profile is a "picture" of building conditions from the perspective of indoor air quality. A review of construction and operating records, combined with an inspection of building conditions, helps to reveal potential indoor air problems and identify building areas that require special attention to prevent problems in the future. Baseline data collected for the IAQ profile can facilitate later investigations, should problems arise. *Section 4* suggests a three-stage approach to developing an IAQ profile and describes the products of each stage.

Section 5: Managing Buildings for Good IAQ

Many indoor air problems can be prevented by following common sense recommendations, such as: maintain good sanitation, provide adequate ventilation, and isolate pollutant sources. Other preventive measures may require a careful review of job descriptions, contracts, supplies, and schedules. It is important to designate an IAQ manager to bear responsibility for coordinating the effort in your building. *Section 5* discusses key elements to include in your IAQ management plan.

Tab III: Resolving IAQ Problems

Section 6: Diagnosing IAQ Problems

Most IAQ investigations begin in response to a complaint from one or more building occupants. IAQ complaints can affect entire buildings or be limited to areas as small as an individual work station. The goal of the investigation is to resolve the complaint without causing other problems.

Section 6 describes a variety of information-gathering strategies used to identify the cause of an IAQ problem. This section provides suggestions for in-house staff who have been given the responsibility of investigating the problem. It will also help building management to understand and oversee the activities of any outside professionals who may be brought in to assist in the investigation.

Section 7: **Mitigating IAQ Problems**

The basic approaches to mitigating indoor air quality problems are: control of pollutant sources; modifications to the ventilation system; air cleaning; and control of exposures to occupants. Successful mitigation often involves a combination of these techniques.

Section 7 provides criteria for judging potential mitigation strategies and for determining whether a problem has been solved. It includes brief descriptions of common indoor air quality problems and possible solutions.

Section 8: **Hiring Professional Assistance to Solve an IAQ Problem**

Indoor air quality is an emerging and interdisciplinary field. *Section 8* provides guidance in hiring professional assistance if you decide that outside expertise is needed to determine the cause of an IAQ problem.

Tab IV: Appendices

Appendix A: **Common IAQ Measurements – A General Guide**

Appendix A describes measurement techniques that are commonly used for IAQ investigations. If you are responsible for developing an IAQ profile or investigating an IAQ complaint, *Appendix A* provides suggestions for collecting and interpreting information on: temperature and humidity; airflow patterns; carbon dioxide; ventilation (outdoor) air quantities; and commonly measured environmental contaminants.

Appendix B: **HVAC Systems and IAQ**

Appendix B presents basic information on HVAC system designs and components and their effects on indoor air quality. This appendix is designed to accompany the HVAC Checklists in Tab V.

Appendix C: **Moisture, Mold and Mildew**

Appendix C discusses indoor moisture and its relationship to mold and mildew growth. The role of humidity in creating mold and mildew problems is often misunderstood because relative humidity readings taken in the breathing zone of an occupied space give little indication of conditions at the wall and ceiling surfaces or in the wall cavities. This appendix describes ways in which to evaluate how moisture may be causing indoor air quality problems and how successful different mitigation measures may be in reducing those problems.

Appendix D: **Asbestos**

Appendix D is a brief discussion of asbestos. If asbestos is a concern in your building, this appendix and the *Appendix G* section will direct you to sources of detailed guidance.

Appendix E: **Radon**

Appendix E is a brief discussion of radon. To learn more about how to check for radon in your building, refer to this appendix. *Appendix G* will direct you to other sources of information.

***Appendix F:* Glossary and Acronyms**

Appendix F explains scientific and engineering terminology that may be unfamiliar to some readers.

***Appendix G:* Resources**

Appendix G is intended for readers who want to pursue more detailed information about indoor air quality. It includes the names, addresses, and telephone numbers of Federal, State, and private sector organizations with interests related to IAQ, as well as a list of selected publications.

Contaminant emission and movement in buildings is an emerging field of study. Building owners, facility managers, and engineers are urged to keep abreast of new information through professional journals and seminars in addition to relying on the guidance presented in this document.

Tab V: Indoor Air Quality Forms

Tab V contains a full set of the forms described in Tabs II and III. Building managers are encouraged to reproduce and use these blank forms. You may want to modify elements of these forms to reflect conditions in your particular building.

WARNING

Please note the following as you prepare to use this manual:

- Modification of building functions to remedy air quality complaints may create other problems. A thorough understanding of all of the factors that interact to create indoor quality problems can help to avoid this undesirable outcome.
- The guidance in this document is not intended as a substitute for appropriate emergency action in the event of a hazardous situation that may be imminently threatening to life or safety.
- The implementation of mitigation recommendations reached as a result of an indoor air quality evaluation should always be done in accordance with local laws and good practice. Changes to the overall design and operation of the building may necessitate the involvement of a registered professional engineer or other registered or certified professionals.
- In the event that medical records are utilized in the course of evaluating an IAQ problem, appropriate legal confidentiality must be maintained.

Factors Affecting Indoor Air Quality

2

The indoor environment in any building is a result of the interaction between the site, climate, building system (original design and later modifications in the structure and mechanical systems), construction techniques, contaminant sources (building materials and furnishings, moisture, processes and activities within the building, and outdoor sources), and building occupants.

The following four elements are involved in the development of indoor air quality problems:

Source: there is a source of contamination or discomfort indoors, outdoors, or within the mechanical systems of the building.

HVAC: the HVAC system is not able to control existing air contaminants and ensure thermal comfort (temperature and humidity conditions that are comfortable for most occupants).

Pathways: one or more pollutant pathways connect the pollutant source to the occupants and a driving force exists to move pollutants along the pathway(s).

Occupants: building occupants are present.

It is important to understand the role that each of these factors may play in order to prevent, investigate, and resolve indoor air quality problems.

SOURCES OF INDOOR AIR CONTAMINANTS

Indoor air contaminants can originate within the building or be drawn in from outdoors. If contaminant sources are not controlled, IAQ problems can arise, even if the HVAC system is properly designed and well-maintained. It may be helpful to think of air pollutant sources as fitting into one of the categories that follow. The examples given for each category are not intended to be a complete list.

Sources Outside Building

Contaminated outdoor air
- pollen, dust, fungal spores
- industrial pollutants
- general vehicle exhaust

Emissions from nearby sources
- exhaust from vehicles on nearby roads or in parking lots, or garages
- loading docks
- odors from dumpsters
- re-entrained (drawn back into the building) exhaust from the building itself or from neighboring buildings
- unsanitary debris near the outdoor air intake

Soil gas
- radon
- leakage from underground fuel tanks
- contaminants from previous uses of the site (e.g., landfills)
- pesticides

Moisture or standing water promoting excess microbial growth
- rooftops after rainfall
- crawlspace

Equipment

HVAC system
- dust or dirt in ductwork or other components
- microbiological growth in drip pans, humidifiers, ductwork, coils
- improper use of biocides, sealants, and/or cleaning compounds
- improper venting of combustion products
- refrigerant leakage

Four elements—sources, the HVAC system, pollutant pathways, and occupants—are involved in the development of IAQ problems.

Given our present knowledge, it is difficult to relate complaints of specific health effects to exposures to specific pollutant concentrations, especially since the significant exposures may be to low levels of pollutant mixtures.

Non-HVAC equipment

- emissions from office equipment (volatile organic compounds, ozone)
- supplies (solvents, toners, ammonia)
- emissions from shops, labs, cleaning processes
- elevator motors and other mechanical systems

Human Activities

Personal activities

- smoking
- cooking
- body odor
- cosmetic odors

Housekeeping activities

- cleaning materials and procedures
- emissions from stored supplies or trash
- use of deodorizers and fragrances
- airborne dust or dirt (e.g., circulated by sweeping and vacuuming)

Maintenance activities

- microorganisms in mist from improperly maintained cooling towers
- airborne dust or dirt
- volatile organic compounds from use of paint, caulk, adhesives, and other products
- pesticides from pest control activities
- emissions from stored supplies

Building Components and Furnishings

Locations that produce or collect dust or fibers

- textured surfaces such as carpeting, curtains, and other textiles
- open shelving
- old or deteriorated furnishings
- materials containing damaged asbestos

Unsanitary conditions and water damage

- microbiological growth on or in soiled or water-damaged furnishings
- microbiological growth in areas of surface condensation
- standing water from clogged or poorly designed drains
- dry traps that allow the passage of sewer gas

Chemicals released from building components or furnishings

- volatile organic compounds or
- inorganic compounds

Other Sources

Accidental events

- spills of water or other liquids
- microbiological growth due to flooding or to leaks from roofs, piping
- fire damage (soot, PCBs from electrical equipment, odors)

Special use areas and mixed use buildings

- smoking lounges
- laboratories
- print shops, art rooms
- exercise rooms
- beauty salons
- food preparation areas

Redecorating/remodeling/repair activities

- emissions from new furnishings
- dust and fibers from demolition
- odors and volatile organic and inorganic compounds from paint, caulk, adhesives
- microbiologicals released from demolition or remodeling activities

Indoor air often contains a variety of contaminants at concentrations that are far below any standards or guidelines for occupational exposure. Given our present knowledge, it is difficult to relate complaints of specific health effects to exposures to specific pollutant concentrations, especially since the significant exposures may be to low levels of pollutant mixtures.

HVAC SYSTEM DESIGN AND OPERATION

The HVAC system includes all heating, cooling, and ventilation equipment serving a building: furnaces or boilers, chillers, cooling towers, air handling units, exhaust fans, ductwork, filters, steam (or heating water) piping. Most of the HVAC discussion in this document applies both to central HVAC systems and to individual components used as stand-alone units.

A properly designed and functioning HVAC system:

- provides thermal comfort
- distributes adequate amounts of outdoor air to meet ventilation needs of all building occupants
- isolates and removes odors and contaminants through pressure control, filtration, and exhaust fans

Thermal Comfort

A number of variables interact to determine whether people are comfortable with the temperature of the indoor air. The activity level, age, and physiology of each person affect the thermal comfort requirements of that individual. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 55-1981 describes the temperature and humidity ranges that are comfortable for most people engaged in largely sedentary activities. That information is summarized on page 57. The ASHRAE standard assumes "normal" indoor clothing. Added layers of clothing reduce the rate of heat loss.

Uniformity of temperature is important to comfort. When the heating and cooling needs of rooms within a single zone change at different rates, rooms that are served by a single thermostat may be at different temperatures. Temperature stratification is a common problem caused by convection, the tendency of light, warm air to rise and heavier, cooler air to sink. If air is not properly mixed by the ventilation system, the temperature near the ceiling can be several degrees warmer than at floor level. Even if air is properly mixed, uninsulated floors over unheated spaces can create discomfort in some climate zones. Large fluctuations of indoor temperature can also occur when controls have a wide "dead band" (a temperature range within which neither heating nor cooling takes place).

Radiant heat transfer may cause people located near very hot or very cold surfaces to be uncomfortable even though the thermostat setting and the measured air temperature are within the comfort range. Buildings with large window areas sometimes have acute problems of discomfort due to radiant heat gains and losses, with the locations of complaints shifting during the day as the sun angle changes. Large vertical surfaces can also produce a significant flow of naturally-convecting air, producing complaints of draftiness. Adding insulation to walls helps to moderate the temperature of interior wall surfaces. Closing curtains reduces heating from direct sunlight and isolates building occupants from exposure to window surfaces (which, lacking insulation, are likely to be much hotter or colder than the walls).

Humidity is a factor in thermal comfort. Raising relative humidity reduces the ability to lose heat through perspiration and evaporation, so that the effect is similar to raising the temperature. Humidity extremes can also create other IAQ problems. Excessively high or low relative humidities can produce discomfort, while high relative humidities can promote the growth of mold and mildew (see *Appendix C*).

Ventilation to Meet Occupant Needs

Most air handling units distribute a blend of outdoor air and recirculated indoor air. HVAC designs may also include units that introduce 100% outdoor air or that simply transfer air within the building. Uncontrolled quantities of outdoor air enter buildings by infiltration through windows, doors, and gaps in the exterior construction. Thermal comfort and ventilation needs are met by supplying "conditioned" air (a blend of outdoor and recirculated air that has been filtered, heated or cooled, and sometimes humidified or dehumidified).

A number of variables, including personal activity levels, uniformity of temperature, radiant heat gain or loss, and humidity, interact to determine whether people are comfortable with the temperature of the indoor air.

Large buildings often have interior ("core") spaces in which constant cooling is required to compensate for heat generated by occupants, equipment, and lighting, while perimeter rooms may require heating or cooling depending on outdoor conditions.

> The amount of outdoor air considered adequate for proper ventilation has varied substantially over time. The current guideline issued by ASHRAE is Standard 62-1989.

Two of the most common HVAC designs used in modern public and commercial buildings are **constant volume** and **variable air volume** systems. Constant volume systems are designed to provide a constant airflow and to vary the air temperature to meet heating and cooling needs. The percentage of outdoor air may be held constant, but is often controlled either manually or automatically to vary with outdoor temperature and humidity. Controls may include a minimum setting that should allow the system to meet ventilation guidelines for outdoor air quantities under design conditions.

Variable air volume (VAV) systems condition supply air to a constant temperature and ensure thermal comfort by varying the airflow to occupied spaces. Most early VAV systems did not allow control of the outdoor air quantity, so that a decreasing amount of outdoor air was provided as the flow of supply air was reduced. Some more recent designs ensure a minimum supply of outdoor air with static pressure devices in the outdoor air stream. Additional energy-conserving features such as economizer control or heat recovery are also found in some buildings.

Good quality design, installation, and testing and balancing are critically important to the proper operation of all types of HVAC systems, especially VAV systems, as are regular inspections and maintenance. (See *Appendix B* for further discussion of HVAC system types.)

The amount of outdoor air considered adequate for proper ventilation has varied substantially over time. The current guideline issued by ASHRAE is ASHRAE Standard 62-1989. The building code that was in force when your building HVAC system was designed may well have established a lower amount of ventilation (in cubic feet of outdoor air per minute per person) than is currently recommended. (A table of outdoor air quantities recommended by ASHRAE is reproduced on page 136 in *Appendix B.* Note that other important aspects of the standard are not included in this table.)

Control of Odors and Contaminants

One technique for controlling odors and contaminants is to dilute them with outdoor air. Dilution can work only if there is a consistent and appropriate flow of supply air that mixes effectively with room air. The term "ventilation efficiency" is used to describe the ability of the ventilation system to distribute supply air and remove internally generated pollutants. Researchers are currently studying ways to measure ventilation efficiency and interpret the results of those measurements.

Another technique for isolating odors and contaminants is to design and operate the HVAC system so that pressure relationships between rooms are controlled. This control is accomplished by adjusting the air quantities that are supplied to and removed from each room. If more air is supplied to a room than is exhausted, the excess air leaks out of the space and the room is said to be under **positive pressure**. If less air is supplied than is exhausted, air is pulled into the space and the room is said to be under **negative pressure**.

Control of pressure relationships is critically important in mixed use buildings or buildings with special use areas. Lobbies and buildings in general are often designed to operate under positive pressure to prevent or minimize the infiltration of unconditioned air, with its potential to cause drafts and introduce dust, dirt, and thermal discomfort. Without proper operation and maintenance, these pressure differences are not likely to remain as originally designed.

A third technique is to use local exhaust systems (sometimes known as dedicated exhaust ventilation systems) to isolate and remove contaminants by maintaining negative pressure in the area around the contaminant source. Local exhaust can be linked to the operation of a particular piece of equipment (such as a kitchen range) or used to treat an entire room (such as a smoking lounge or custodial closet). Air should be exhausted to the outdoors, **not** recirculated, from locations which produce significant odors and high concentrations of contaminants (such as copy rooms, bathrooms, kitchens, and beauty salons).

Spaces where local exhaust is used must be provided with make-up air and the local exhaust must function in coordination with the rest of the ventilation system. Under some circumstances, it may be acceptable to transfer conditioned air from relatively clean parts of a building to comparatively dirty areas and use it as make-up air for a local exhaust system. Such a transfer can achieve significant energy savings.

Air cleaning and filtration devices designed to control contaminants are found as components of HVAC systems (for example, filter boxes in ductwork) and can also be installed as independent units. The effectiveness of air cleaning depends upon proper equipment selection, installation, operation, and maintenance. Caution should be used in evaluating the many new technological developments in the field of air cleaning and filtration.

POLLUTANT PATHWAYS AND DRIVING FORCES

Airflow patterns in buildings result from the combined action of mechanical ventilation systems, human activity, and natural forces. Pressure differentials created by these forces move airborne contaminants from areas of relatively higher pressure to areas of relatively lower pressure through any available openings.

The HVAC system is generally the predominant pathway and driving force for air movement in buildings. However, all of a building's components (walls, ceilings, floors, penetrations, HVAC equipment, and occupants) interact to affect the distribution of contaminants.

Chases, crawlspaces, and other hidden spaces can be both sources and pathways for pollutants.

For example, as air moves from supply registers or diffusers to return air grilles, it is diverted or obstructed by partitions, walls, and furnishings, and redirected by openings that provide pathways for air movement. On a localized basis, the movement of people has a major impact on the movement of pollutants. Some of the pathways change as doors and windows open and close. It is useful to think of the entire building — the rooms and the connections (e.g., chases, corridors, stairways, elevator shafts) between them — as part of the air distribution system.

Natural forces exert an important influence on air movement between zones and between the building's interior and exterior. Both the **stack effect** and **wind** can overpower a building's mechanical system and disrupt air circulation and ventilation, especially if the building envelope is leaky.

Stack effect is the pressure driven flow produced by convection (the tendency of

The basic principle of air movement from areas of relatively higher pressure to areas of relatively lower pressure can produce many patterns of contaminant distribution.

warm air to rise). The stack effect exists whenever there is an indoor-outdoor temperature difference and becomes stronger as the temperature difference increases. As heated air escapes from upper levels of the building, indoor air moves from lower to upper floors, and replacement outdoor air is drawn into openings at the lower levels of buildings. Stack effect airflow can transport contaminants between floors by way of stairwells, elevator shafts, utility chases, or other openings.

Wind effects are transient, creating local areas of high pressure (on the windward side) and low pressure (on the leeward side) of buildings. Depending on the leakage openings in the building exterior, wind can affect the pressure relationships within and between rooms.

The basic principle of air movement from areas of relatively higher pressure to areas of relatively lower pressure can produce many patterns of contaminant distribution, including:

- local circulation in the room containing the pollutant source
- air movement into adjacent spaces that are under lower pressure (*Note*: Even if two rooms are both under positive pressure compared to the outdoors, one room is usually at a lower pressure than the other.)
- recirculation of air within the zone containing the pollutant source or in adjacent zones where return systems overlap
- movement from lower to upper levels of the building
- air movement into the building through either infiltration of outdoor air or reentry of exhaust air

Air moves from areas of higher pressure to areas of lower pressure through any available openings. A small crack or hole can admit significant amounts of air if the pressure differentials are high enough (which may be very difficult to assess.)

Even when the building as a whole is maintained under positive pressure, there is always some location (for example, the outdoor air intake) that is under negative pressure relative to the outdoors. Entry of contaminants may be intermittent, occurring only when the wind blows from the direction of the pollutant source. The interaction between pollutant pathways and intermittent or variable driving forces can lead to a single source causing IAQ complaints in areas of the building that are distant from each other and from the source.

BUILDING OCCUPANTS

The term “building occupants” is generally used in this document to describe people who spend extended time periods (e.g., a full workday) in the building. Clients and visitors are also occupants; they may have different tolerances and expectations from those who spend their entire workdays in the building, and are likely to be more sensitive to odors.

Groups that may be particularly susceptible to effects of indoor air contaminants include, but are not limited to:

- allergic or asthmatic individuals
- people with respiratory disease
- people whose immune systems are suppressed due to chemotherapy, radiation therapy, disease, or other causes
- contact lens wearers

Some other groups are particularly vulnerable to exposures of certain pollutants or pollutant mixtures. For example, people with heart disease may be more affected by exposure at lower levels of carbon monoxide than healthy individuals. Children exposed to environmental tobacco smoke have been shown to be at higher risk of respiratory illnesses and those exposed to nitrogen dioxide have been shown to be at higher risk from respiratory infections.

Because of varying sensitivity among people, one individual may react to a particular IAQ problem while surrounding occupants have no ill effects. (Symptoms that are limited to a single person can also occur when only one work station receives the bulk of the pollutant dose.) In other cases, complaints may be widespread.

A single indoor air pollutant or problem can trigger different reactions in different people. Some may not be affected at all. Information about the types of symptoms can sometimes lead directly to solutions. However, symptom information is more likely to be useful for identifying the timing and conditions under which problems occur.

Types of Symptoms and Complaints

The effects of IAQ problems are often non-specific symptoms rather than clearly defined illnesses. Symptoms commonly attributed to IAQ problems include:

- headache
- fatigue
- shortness of breath
- sinus congestion
- cough
- sneezing
- eye, nose, and throat irritation
- skin irritation
- dizziness
- nausea

All of these symptoms, however, may also be caused by other factors, and are not necessarily due to air quality deficiencies.

"Health" and "comfort" are used to describe a spectrum of physical sensations. For example, when the air in a room is slightly too warm for a person's activity level, that person may experience mild discomfort. If the temperature continues to rise, discomfort increases and symptoms such as fatigue, stuffiness, and headaches can appear.

Some complaints by building occupants are clearly related to the discomfort end of the spectrum. One of the most common IAQ complaints is that "there's a funny smell in here." Odors are often associated with a perception of poor air quality, whether or not they cause symptoms. Environmental stressors such as improper lighting, noise, vibration, overcrowding, ergonomic stressors, and job-related psychosocial problems (such as job stress) can produce symptoms that are similar to those associated with poor air quality.

The term **sick building syndrome (SBS)** is sometimes used to describe cases in which building occupants experience acute health and comfort effects that are apparently linked to the time they spend in the building, but in which no specific illness or cause can be identified. The complaints may be localized in a particular room or zone or may be widespread throughout the building. Many different symptoms have been associated with SBS, including respiratory complaints, irritation, and fatigue. Analysis of air samples often fails to detect high concentrations of specific contaminants. The problem may be caused by any or all of the following:

- the combined effects of multiple pollutants at low concentrations
- other environmental stressors (e.g., overheating, poor lighting, noise)
- ergonomic stressors
- job-related psychosocial stressors (e.g., overcrowding, labor-management problems)
- unknown factors

Building-related illness (BRI) is a term referring to illness brought on by exposure to the building air, where symptoms of diagnosable illness are identified (e.g., certain allergies or infections) and can be directly attributed to environmental agents in the air. Legionnaire's disease and hypersensitivity pneumonitis are examples of BRI that can have serious, even life-threatening consequences.

Environmental stressors such as improper lighting, noise, vibration, overcrowding, ergonomic stressors, and job-related psychosocial problems (such as job stress) can produce symptoms that are similar to those associated with poor air quality.

A small percentage of the population may be sensitive to a number of chemicals in indoor air, each of which may occur at very low concentrations. The existence of this condition, which is known as **multiple chemical sensitivity (MCS)**, is a matter of considerable controversy. MCS is not currently recognized by the major medical organizations, but medical opinion is divided, and further research is needed. The applicability of access for the disabled and worker's compensation regulations to people who believe they are chemically sensitive may become concerns for facility managers.

Sometimes several building occupants experience rare or serious health problems (e.g., cancer, miscarriages, Lou Gehrig's disease) over a relatively short time period. These **clusters** of health problems are occasionally blamed on indoor air quality, and can produce tremendous anxiety among building occupants. State or local Health Departments can provide advice and assistance if clusters are suspected. They may be able to help answer key questions such as whether the apparent cluster is actually unusual and whether the underlying cause could be related to IAQ.

Effective Communication

3

This section discusses establishing and maintaining a communication system that can help prevent indoor air quality problems and resolve problems coopera-tively if they do arise. If you are currently responding to an indoor air quality complaint, you may want to skip ahead to the discussion of *Communicating to Resolve IAQ Problems* on page 15.

COMMUNICATING TO PREVENT IAQ PROBLEMS

Effective communication can encourage building occupants to improve their work environment through positive contributions. The following objectives should be kept in mind while reviewing and revising your current approach to communicating with occupants:

- provide accurate information about factors that affect indoor air quality
- clarify the responsibilities of each party (e.g., building management, staff, tenants, contractors)
- establish an effective system for logging and responding to complaints should they occur

Provide Accurate Information

Many indoor air quality problems can be prevented if staff and building occupants understand how their activities affect IAQ. You may already have a health and safety committee functioning to promote good working conditions. If so, it is easy to add indoor air quality to their list of concerns. If you do not have a health and safety committee, consider establishing one or setting up a joint management-tenant IAQ task force. Whatever its official designation, such a group can help to disseminate information about indoor air quality, bring potential problems to the attention of building staff and management, and foster a sense of shared responsibility for maintaining a safe and comfortable indoor environment.

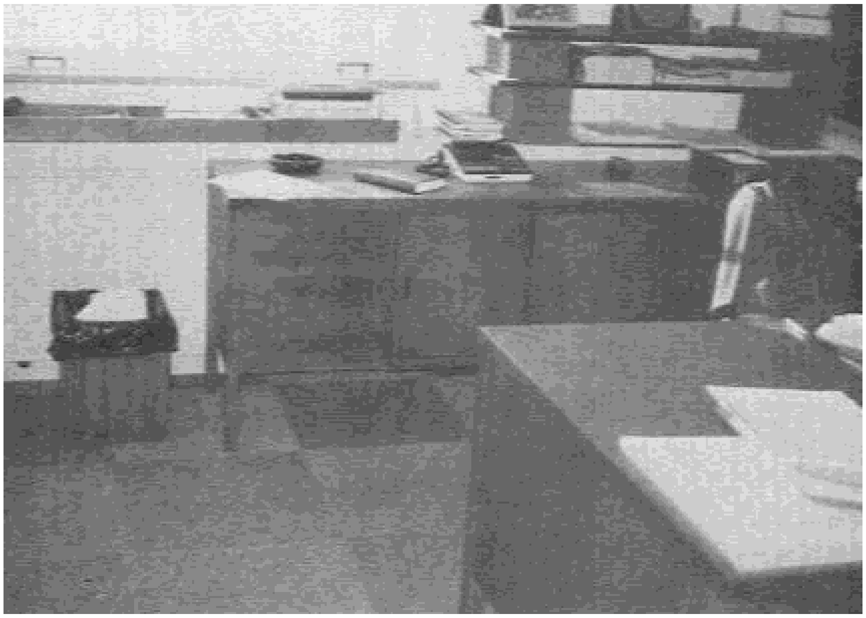
The group will be most successful if it represents the diverse interests in the building, including:

- building owner
- building manager
- facility personnel
- health and safety officials
- tenants and/or other occupants who are not facility staff
- union representatives (or other worker representatives)

Clarify Responsibilities

It is important to define the responsibilities of building management, staff, and occupants in relation to indoor air quality. These responsibilities can be formalized by incorporating them into documents such as employee manuals or lease agreements.

The occupant in this room covered the supply air vents with papers. Whether this was done to reduce uncomfortable drafts or to provide more shelf space, the result can disrupt the air flow, not only through this room but elsewhere in the building. By tampering with the air handling system, occupants can unintentionally cause complaints in other areas.



Use of Space: Educate occupants about the permitted uses and maximum occupancy of different areas within the building and make sure that appropriate ventilation is provided for the activities that are permitted. Indoor air quality complaints often arise in mixed-use buildings. For example, kitchen staff expect food odors as part of their work, but nearby office workers may find cooking odors distracting and unpleasant. Problems can also arise when old tenants leave and new arrivals introduce new uses of the building.

Occupancy Rate: Inform occupants about the importance of keeping the building management informed about significant changes in the number of people regularly using particular areas of the building. The ventilation systems in buildings are designed and operated to supply air to projected ranges of occupants. If the occupancy rate becomes a problem, it may be helpful to refer to a standard reference such as ASHRAE Standard 62-1989 to show occupants that keeping occupancy within the ventilation capacity serves the goal of providing a quality work environment and is not an arbitrary decision by building management.

Modifications: Review plans that may involve increases in the number of occupants, relocation of walls or partitions, installation of new equipment, or changes in the use of space. Building owners, facility managers, and occupants share responsibility for monitoring new equipment installation and changes in the use of space. The review process allows potential indoor air quality problems to be identified so that the HVAC system can be modified as needed. Only authorized maintenance personnel should adjust air supply or exhaust vents; however, if occupants are expected to follow such a "hands-off" policy, facility management must respond promptly to IAQ complaints.

Notification of planned activities: Establish a procedure for informing tenants before the start of activities that produce odors or contaminants (e.g., maintenance, pest control, repair, remodeling, redecorating).

MANAGEMENT AND OCCUPANT COOPERATION ON INDOOR AIR QUALITY

The State of Wisconsin's "Quality Building Management" system has helped to unite the diverse interests involved in operating and using State office buildings. Tenants and facility personnel volunteers to serve on teams, working cooperatively to improve the quality of the indoor environment.

Each team was assigned a specific area for which it drafted "Ideal Building Standards." Air quality was one such area; others included elevators, rest rooms, and work spaces. The IAQ teams were trained in conducting research; toured mechanical rooms to achieve a better understanding of building operations; read articles; and listened to presentations on IAQ, ventilation, and related topics.

The proposed "Ideal Building Standards" were reviewed with other tenants and then used as a basis for Quality Improvement Plans. Some elements of the Quality Improvement Plans identify responsibilities of the tenants, such as adopting good housekeeping practices to improve the work environment and facilitate cleaning. Responsibilities identified as belonging to building management are reflected in work plans and budget decisions.

Since implementation of this management system, interactions between building management and tenants have improved. Tenants actively seek out management staff to discuss concerns. However, they are also more willing to review their own actions when looking for potential causes of IAQ problems.

Establish a System for Responding to Complaints

Many organizations have established procedures for responding to occupant complaints that can be modified to include indoor air quality concerns. To avoid frustrating delays, building occupants need to know how to express their complaints about IAQ. More importantly, they need to know how to locate responsible staff and where to obtain complaint forms. This information can be posted on bulletin boards, circulated in memos or newsletters, or publicized by some other means.

Complaints should be handled promptly, with every incident given serious attention. It is advisable to establish a recordkeeping system that cross-references documentation on complaints with records of equipment operation and maintenance. The recordkeeping system can help to resolve complaints by collecting information in a form that highlights patterns of problems (for example, complaints that occur at a regular time of day or in the same area of the building). The **IAQ Complaint Form** and **Incident Log** shown here and on the following page (and also reproduced in Tab V) can be used to track complaints related to the indoor environment.

Sample Form

Indoor Air Quality Complaint Form

This form should be used if your complaint may be related to indoor air quality. Indoor air quality problems include concerns with temperature control, ventilation, and air pollutants. Your observations can help to resolve the problem as quickly as possible. Please use the space below to describe the nature of the complaint and any potential causes.

We may need to contact you to discuss your complaint. What is the best time to reach you?

____

So that we can respond promptly, please return this form to:

____

IAQ Manager or Contact Person

SEE COMPLETE FORM PAGE 181

COMMUNICATING TO RESOLVE IAQ PROBLEMS

In many cases, building managers may be alerted to potential indoor air quality problems by complaints from occupants. The complaints can be vague, to the effect that one or more people feel “sick” or “uncomfortable” or that someone has noticed an unusual odor. They may be specific, blaming a particular material as the cause of discomfort or health problems. People are usually reacting to a real problem, so their complaints should be taken seriously. However, they may attribute their symptoms to the wrong cause, so their theories about the problem should be heard respectfully but weighed cautiously.

Indoor air quality problems can sometimes be identified and resolved quickly. On other occasions, complaints originate from the interaction of several variables, and detailed investigation may be necessary in order to resolve the problem.

The Importance of Responding to IAQ Complaints

Listening and responding to building occupants is critical to achieving a successful resolution of indoor air quality complaints. IAQ complaints may be grounded in poor indoor air quality, thermal conditions, noise, glare, or even job stresses. However, it is in the building manager’s best interest to respond to all complaints about the indoor environment promptly and seriously and to establish credibility through open communication with building occupants. The biggest mistake that building managers can make in the face of an IAQ complaint is to underestimate the problems that can result if building occupants believe that no action is being taken or that important information is being withheld. Without open communication, any IAQ problem can become complicated by anxiety, frustration, and distrust, delaying its resolution.

Paying attention to communication, as well as problem-solving, helps to ensure

Sample Form

Incident Log

			Investigation Record (check the forms that were used)										
File Number	Date	Problem Location	Complaint Form	Occupant Interview	Occupant Diary	Log of Activities	Zone/Room Record	HVAC Checklist	Pollutant Pathway	Source Inventory	Hypothesis Form	Outcome / Comments	Log Entry By (initials)

SEE COMPLETE FORM PAGE 183

The messages to convey are that management believes it is important to provide a healthy and safe building, that good indoor air quality is an essential component of a healthful indoor environment, and that complaints about indoor air quality are taken seriously.

the support and cooperation of building occupants as the complaint is investigated and resolved. The messages to convey are that management believes it is important to provide a healthy and safe building, that good indoor air quality is an essential component of a healthful indoor environment, and that complaints about indoor air quality are taken seriously.

Communications, whether they occur in conversations or in writing, should include the following information:

- what types of complaints management has received
- management's policy in regard to providing a healthy and safe environment and responding to occupant complaints
- what management has done to date (e.g., collecting data, responding to the problem)
- what management plans to do in order to further investigate and correct the problem (including the fact that outside consultants have been called in, if they have been)
- the names and telephone numbers of appropriate facility management, medical, or health and safety staff to whom the occupants should turn if they have additional complaints or questions, or if they have information that may help in resolving the complaints

Maintaining the Lines of Communication

Make certain that occupants know how to contact the responsible personnel who can receive and respond to IAQ complaints. Tenants may also have an internal system for channeling complaints, for example through a health and safety representative, supervisor, or company doctor.

Indoor air quality complaints that can be resolved quickly and that involve small numbers of people (e.g., annoying but harmless odors from an easily-identified source) can be handled matter-of-factly like other minor problems without risking confusion and bad feeling among other building occupants. Communication becomes a more critical issue when there are delays in identifying and resolving the problem and when serious health concerns are involved.

If the problem seems to be widespread or potentially serious, it is advisable to work with your health and safety committee. If you do not have a health and safety committee, consider forming one, or establishing a joint management-tenant IAQ task force. (See the discussion on page 13.)

Productive relations will be enhanced if occupants are given basic information during the process of investigation and mitigation. Potential critics can become allies if they are invited to be part of the problem-solving process and become better educated about IAQ and building operations. Building managers may be understandably reluctant to share test results or consultants' reports with their tenants or employees, but secrecy in such matters can backfire if information leaks out at a later time.

Building management staff can be encouraged to talk directly with occupants both at the time a complaint occurs and later during a diagnostic investigation. Their observations about patterns of symptoms or building conditions may provide helpful information.

Confidentiality of records can be important to occupants, especially if they are concerned that IAQ complaints will lead to negative reactions from their employers. There may be legal penalties for violating confidentiality of medical records. By reassuring occupants that privacy will be respected, investigators are more likely to obtain honest and complete information.

It is advisable to explain the nature of investigative activities, so that rumors and suspicions can be countered with factual information. Notices or memoranda can be delivered directly to selected occupants or posted in general use areas. Newsletter articles or other established communication channels can also be used to keep building occupants up-to-date.

Problems can arise from saying either too little or too much. Premature release of information when data-gathering is still incomplete can produce confusion, frustration, and mistrust at a later date. Similar problems can result from incorrect representation of risk — assuming the worst case (or the best). However, if progress reports are not given, people may think nothing (or something terrible) is happening. It is good practice to clear each piece of information with the facility manager, building owner, or legal counsel. Management should attempt to be factual and to the point when presenting information such as:

- the definition of the complaint area based upon the location and distribution of complaints (this may be revised as the investigation progresses)
- the progress of the investigation, including the types of information that are being gathered and ways that occupants can help
- factors that have been evaluated and found not to be causing or contributing to the problem
- how long the investigation might take
- attempts that are being made to improve indoor air quality
- work that remains to be done and the schedule for its completion

Vague discomfort, intermittent symptoms, and complex interactions of job stress with environmental factors, which make IAQ problems difficult to investigate, can also obscure the effects of mitigation efforts. Even after the proper mitigation strategy is in place, it may take days or weeks for contaminants to dissipate and symptoms to disappear. If building occupants are informed that their symptoms may persist for some time after mitigation, the inability to bring instant relief is less likely to be seen as a failure.

If the problem seems to be widespread or potentially serious, it is advisable to work with your health and safety committee. If you do not have a health and safety committee, consider forming one, or establishing a joint management-tenant IAQ task force.

PREVENTING IAQ PROBLEMS

Building Air Quality

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Developing an IAQ Profile

4

An IAQ profile is a description of the features of the building structure, function, and occupancy that impact indoor air quality. When you have completed the IAQ profile, you should have an understanding of the current status of air quality in the building and baseline information on the factors that have a potential for causing problems in the future.

The IAQ profile can help building management to identify potential problem areas and prioritize budgets for maintenance and future modifications. Combined with information on lighting, security, and other important systems, it can become an owner's manual that is specific to your building and that will serve as a reference in a variety of situations.

The key questions to answer while developing the IAQ profile are:

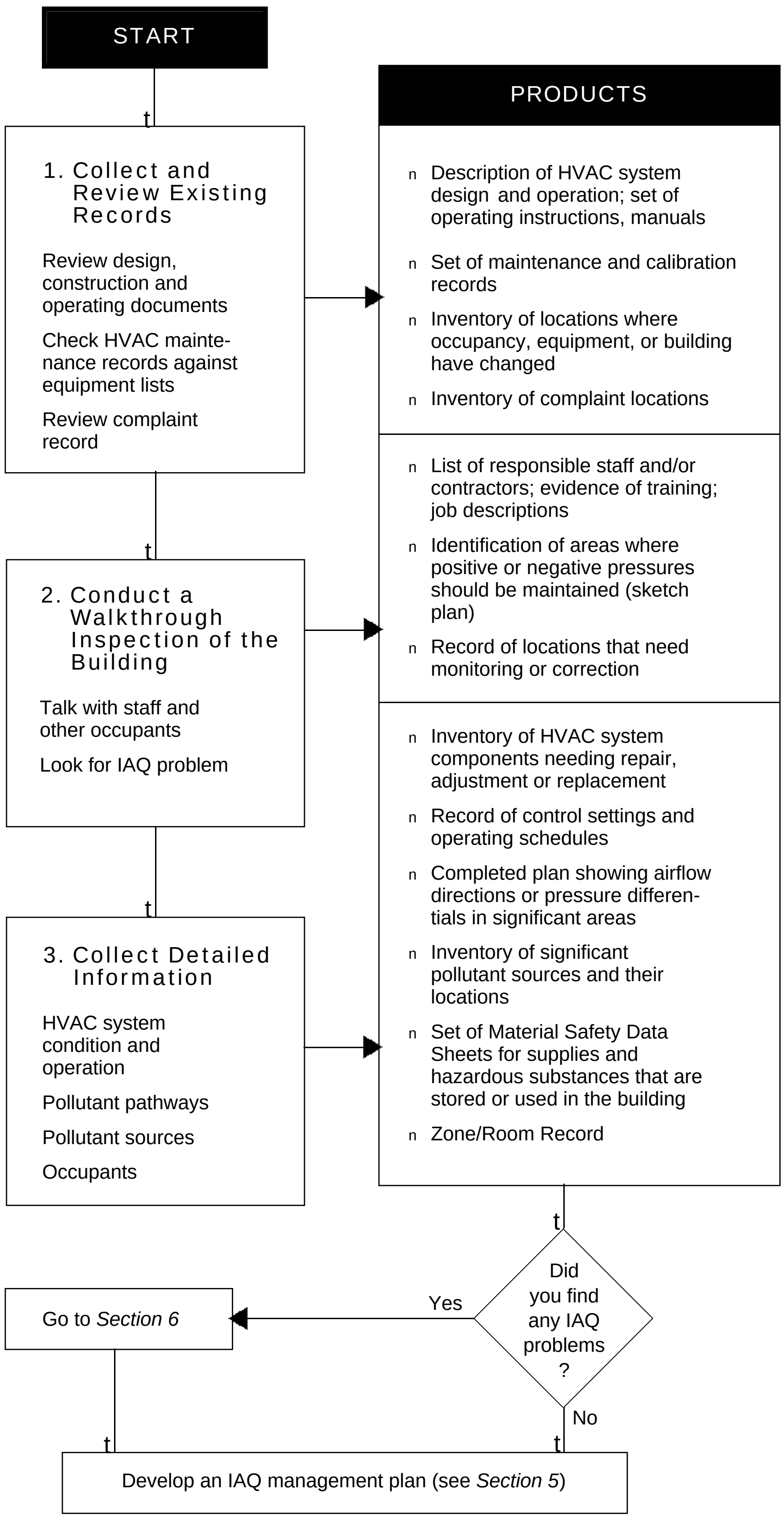
- How was this building originally intended to function? Consider the building components and furnishings, mechanical equipment (HVAC and non-HVAC), and the occupant population and associated activities.
- Is the building functioning as designed? Find out whether it was commissioned. Compare the information from the commissioning to its current condition.
- What changes in building layout and use have occurred since the original design and construction? Find out if the HVAC system has been reset and retested to reflect current usage.
- What changes may be needed to prevent IAQ problems from developing in the future? Consider potential changes in future uses of the building.

After reading this manual to develop a feel for the issues involved in maintaining good indoor air quality in a building, the development of an IAQ profile should become a priority. The process of developing an IAQ profile should require only a modest effort, from a few days to a few weeks of staff time, depending on the complexity of your building and the amount of detailed information collected. The work can be done in pieces over a longer period, if necessary, to fit into a building manager's busy schedule.

Over time, it is desirable to make some actual measurements of airflow, temperature, relative humidity, carbon dioxide (CO_2), and/or pressure differentials (e.g., in each of the air handling zones or other subareas of the building). These measurements provide far better information on current conditions than can be obtained from the plans and specifications, even if as-built records are available.

In addition, few buildings have been adequately commissioned, so the system may never have delivered the airflows shown on the design drawings. In the event of litigation around future IAQ complaints, the value of the IAQ profile as a resource document will be enhanced by real-world measurements. (Refer to *Appendix G* and the ASHRAE standard on commissioning. The EPA document on designing for good indoor air quality, which is due to be published in 1992, will contain a more complete discussion of the process of commissioning buildings.)

FIGURE 4-1: Developing an IAQ Profile



SKILLS REQUIRED TO CREATE AN IAQ PROFILE

Many of the resources necessary for the IAQ profile should already be on hand within your organization. Additional information can be collected by the staff person or persons who have the following skills:

- basic understanding of HVAC system operating principles
- ability to read architectural and mechanical plans and understandmanufacturer's catalog data on equipment
- ability to identify items of office equipment
- ability to work cooperatively with building occupants and gather information about space usage
- ability to collect information about HVAC system operation, equipment condition, and maintenance schedules
- authority to collect information from subcontractors about work schedules and materials used (particularly cleaning and pest control activities)
- ability to understand the practical meaning of the information contained in the Material Safety Data Sheets (MSDSs)

If direct measurements are to be included in the IAQ profile, the staff should have the tools and training to make the following measurements (see *Appendix A* for guidance on air sampling):

- air volumes at supply diffusers and exhaust grilles
- CO_2 concentration
- temperature
- relative humidity
- pressure differentials
- assessment of thermal and ventilation load requirements

Section 8 provides guidance on hiring IAQ professionals if you prefer to use outside expertise to develop your IAQ profile.

STEPS IN AN IAQ PROFILE

The information needed for an IAQ profile is similar to that which is collected when solving indoor air quality problems, but includes the entire building rather than focusing on areas that may have caused an identified problem. The IAQ profile should be an organized body of records that can be referred to in planning for renovations, negotiating leases and contracts, or responding to future complaints.

The process of gathering information for the IAQ profile can be divided into three major stages:

1. Collect and review existing records.
2. Conduct a walkthrough inspection of the building.
3. Collect detailed information on the HVAC system, pollutant pathways, pollutant sources, and building occupancy.

The first two stages should be carried out as quickly as possible, but the third stage can be handled as time allows so that it does not interfere with other staff responsibilities.

PRODUCTS OF THE REVIEW OF EXISTING RECORDS

- a description of the HVAC system design and operation (e.g., original plans and specifications with changes indicated or new sketch plans and notes, commisioning reports, testing and balancing reports)
- a set of operating instructions, maintenance and calibration records for HVAC system components (e.g., fans, dampers, filters, chillers, boilers, and control systems)
- an inventory of locations where architectural or engineering modifications have taken place
- an inventory of locations in which current occupancy or HVAC system operation represents a change from the original design
- an inventory of locations where complaints have been common in the past

1. Collect and Review Existing Records

Review construction and operating documents

Collect any available documents that describe the construction and operation of the building: architectural and mechanical plans, specifications, submittals, sheet metal drawings, commissioning reports, adjusting and balancing reports, inspection records, and operating manuals. Many buildings may lack some or all of these documents. If there are no commissioning reports or balancing reports, actual ventilation quantities may be quite different from those indicated on mechanical design drawings. If there are no operating or maintenance manuals for HVAC equipment, it is difficult for staff to carry out an adequate preventive maintenance program.

Study the original architectural and mechanical design so that you understand the building's layout and intended functions. Identify and note locations in which changes in equipment or room usage create a potential for indoor air quality problems and give them special attention during the walkthrough inspection.

Items of interest and the questions they suggest could include the following:

Commissioning reports

- Was the building properly commissioned when it was first constructed, including testing and balancing of the HVAC system?

Operating manuals

- Do staff members understand how the HVAC equipment is intended to operate?

Remodeled areas

- Has the HVAC system layout been changed to accommodate new walls, rearranged partitions, or similar architectural modifications?

Addition, removal, or replacement of HVAC equipment

- Where the original equipment has been replaced, do the newer units have the same capacity as the originals?
- Has new equipment been properly installed and tested? Where equipment has been removed, is it is no longer needed?

Changes in room use

- Is there a need for additional ventilation (supply and/or exhaust) due to increased occupant population or new activities within any area of the building?
- Have new items of equipment (non-HVAC) been provided with local exhaust where needed? Look for unusual types or quantities of equipment such as copy machines or computer terminals.

Check HVAC maintenance records against equipment lists

Collect your existing maintenance and calibration records and check them against the construction documents (e.g., equipment lists and mechanical plans). See whether all components appear to be receiving regular attention. Equipment that has been installed in inaccessible or out-of-the-way locations is frequently overlooked during routine maintenance. This is particularly true of items such as filter boxes and small capacity exhaust fans.

Review records of complaints

If there is an organized record of past occupant complaints about the building environment, review those complaints to identify building areas that deserve particular attention.

2. Conduct a Walkthrough Inspection of the Building

The intent of the walkthrough inspection is to acquire a good overview of occupant activities and building functions and to look for IAQ problem indicators. No specific forms are suggested for this stage of IAQ profile development. However, the investigator should have a sketch plan of the building, such as a small floor plan showing fire exit, so that his or her notes can be referenced to specific locations.

Detailed measurements of temperature, humidity, airflow, or other parameters are more appropriate to a later stage of profile development. However, chemical smoke can be used to observe airflow patterns and pressure relationships between special use areas or other identified pollutant sources and surrounding rooms. Odors in inappropriate locations (e.g., kitchen odors in a lobby) may indicate that ventilation system components require adjustment or repair. (See *Appendix A* for further discussion of the use of chemical smoke.)

The value of IAQ ventilation measurement tools to your operation will grow as you become more familiar with handling indoor air quality concerns. For example, if you do not own a direct-reading carbon dioxide monitor, it is not necessary to acquire one for the IAQ profile. Those who already have access to this type of instrument can take readings during the walkthrough as a way to obtain baseline

PRODUCTS OF THE WALKTHROUGH INSPECTION

At the end of the walkthrough inspection, you should have:

- List of staff (and contractors) with responsibilities that could affect IAQ, including contact information:
  - names, telephone numbers job descriptions
  - notes on training and experience of building staff
- Notes on the schedules and procedures used in:
  - facilities operation and maintenance
  - housekeeping
  - pest control
- Sketch plan with notes showing:
  - pressure relationships between special use areas and surrounding rooms
  - locations in which general indicators of IAQ problems show the need for close monitoring or corrective action

information about normal operating conditions or identify problem locations. If you begin to suspect that underventilation is a consistent problem, you may decide that it would be helpful to obtain more ventilation monitoring equipment. (See *Appendix A* for further discussion of carbon dioxide and other ventilation measurements.)

Talk with staff and other occupants

A walkthrough inspection provides an opportunity to introduce facility staff and other building occupants to the topic of indoor air quality and to understand current staff (and contractor) responsibilities in relation to housekeeping and maintenance activities. Advance notice of the inspection will make it seem less intrusive and may encourage staff and other occupants to remember important information.

Discussion of routine activities in the building will help to clarify elements that should be included in the IAQ management plan. Ask staff members about their job responsibilities, training and experience. It will be helpful to meet with responsible staff and contractors to discuss:

Facility operation and maintenance (e.g., HVAC, plumbing, electric, interior maintenance)

- HVAC operating schedule (e.g., occupied/unoccupied cycles)
- HVAC maintenance schedule (e.g., filter changes, drain pan maintenance)
- use and storage of chemicals
- schedule of shipping and receiving, handling of vehicles at loading dock
- scheduling and other procedures for isolating odors, dust, and emissions from painting, roof repair, and other contaminant-producing activities
- budgeting (i.e., how do staff members influence budget decisions?)

Housekeeping

- cleaning schedule
- trash storage and schedule of refuse removal
- use and storage of chemicals

Pest control

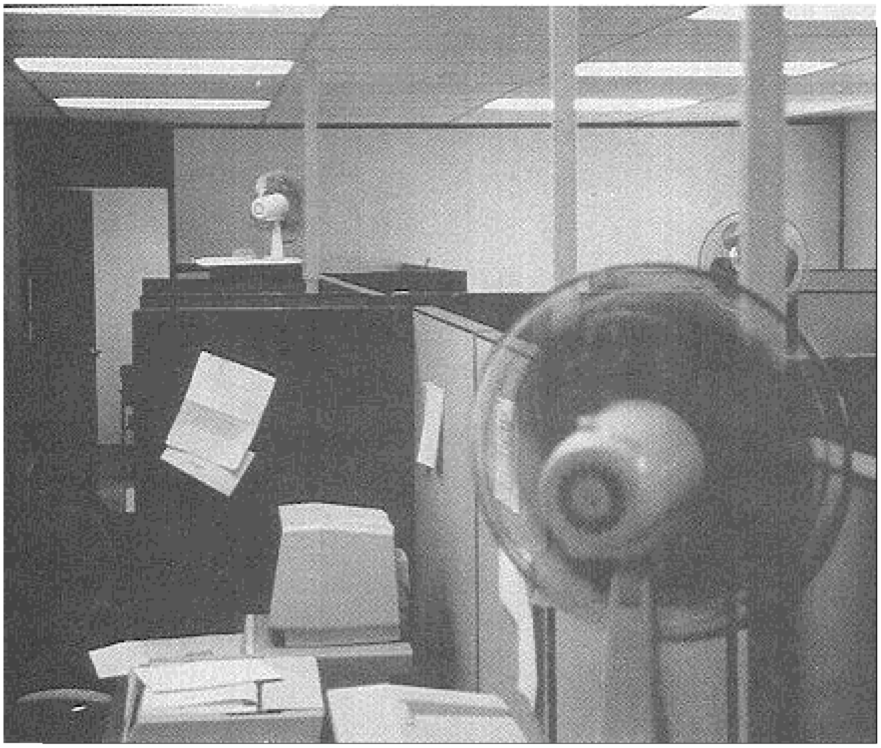
- schedule and location of pesticide applications
- use and storage of chemicals
- pest control activities other than use of pesticides

Look for IAQ problem indicators

The walkthrough inspection can be used to identify areas with a high potential for IAQ problems. The following are general indicators of IAQ problems:

- odors
- dirty or unsanitary conditions (e.g., excessive dust)
- visible fungal growth or moldy odors (often associated with problem of too much moisture)
- sanitary conditions at equipment such as drain pans and cooling towers

Maintenance is more likely to be performed on a routine basis when there is good access to HVAC equipment such as that shown in this photo.



Building occupants who are uncomfortable may try to improve the situation by themselves. The small fans shown above indicate an air circulation or thermal discomfort problem. The irony of this situation is that the fan motors add heat to the air.

- sanitary conditions in equipment such as drain pans and cooling towers
- poorly-maintained filters
- signs of mold or moisture damage at walls (e.g., below windows, at columns, at exterior corners), ceilings, and floors
- staining and discoloration (*Note:* Make sure that stains are removed after leaks are repaired so that there will be visible evidence if the leak recurs.)
- smoke damage (*Note:* If a fire has occurred involving electrical equipment, determine whether PCBs (polychlorinated biphenyls) may have been released from the equipment.)
- presence of hazardous substances
- potential for soil gas entry (e.g., unsealed openings to earth, wet earth smells)
- unsanitary mechanical room, or trash or stored chemicals in mechanical room
- unusual noises from light fixtures or mechanical equipment

In addition to these general indications, some common problems deserve mention:

Inadequate maintenance: Look for leaks of oil, water, or refrigerants around HVAC equipment. Also be aware of signals such as unreplaced burned-out light bulbs in fan chambers and staff members who have difficulty locating specific pieces of equipment. Dry drain traps can also cause indoor air quality problems. If traps are not kept charged with liquid, they could be allowing sewer gas to enter occupied spaces.

Signs of occupant discomfort: Notice uneven temperatures, persistent odors (including tobacco smoke), drafts, sensations of stuffiness. You may find that occupants are attempting to compensate for an HVAC system that doesn't meet their needs. Look for propped-open corridor doors, blocked or taped up diffusers, popped-up ceiling tiles, people using individual fans/ heaters or wearing heavier (or lighter) clothing than normal.

Overcrowding: Future occupant density is estimated when the ventilation system for a building is designed. When the actual number of occupants approaches or exceeds this occupant design capacity, managers may find that IAQ complaints increase. At that point, the outdoor air ventilation rate will have to be increased. However, the ventilation and cooling systems may not have sufficient capacity to handle the increased loads from the current use of the space.

Blocked airflow: Check for under-ventilation caused by obstructed vents, faulty dampers or other HVAC system malfunctions, or from problems within the occupied space. Furniture, papers, or other materials can interfere with air movement around thermostats or block airflow from wall or floor-mounted registers. If office cubicles are used, a small space (i.e., two to four inches) between the bottom of the partitions and the floor may improve air circulation.

Ceiling plenums: Lift a ceiling tile and examine the plenum for potential problems. Walls or full-height partitions that extend to the floor above can obstruct or divert air movement in ceiling plenums unless transfer grilles have been provided. If fire dampers have been installed to allow air circulation through walls or partitions, confirm that the dampers are open. Construction debris and damaged or loose material in the plenum area may become covered with dust and can release particles and fibers.

Heat sources: Be aware of areas that contain unusual types or quantities of equipment such as copy machines or computer terminals. Also look for instances of over-illumination. High concentrations of electrical fixtures and equipment can overwhelm the ventilation and cooling systems.

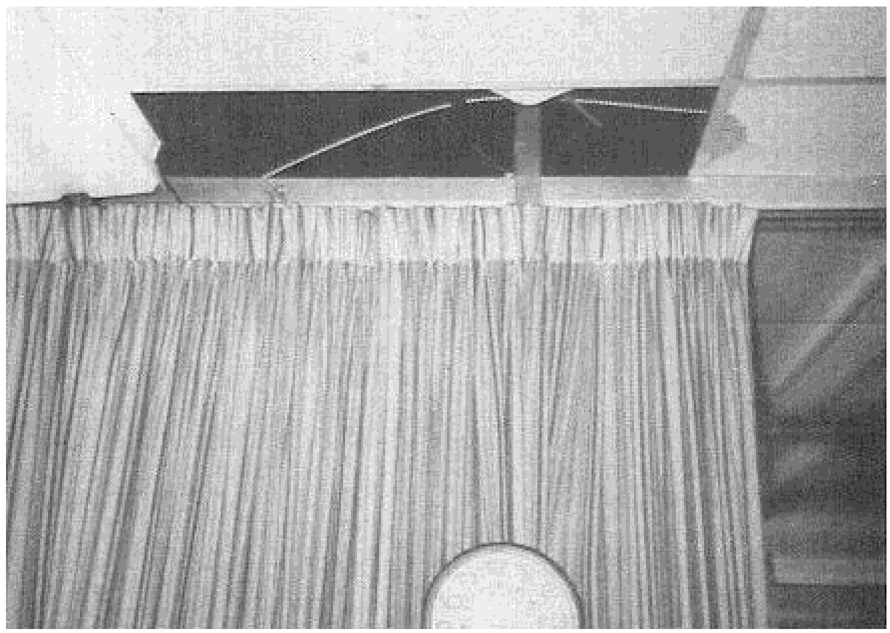
Special use areas: Confirm that the HVAC system maintains appropriate pressure relationships to isolate and contain odors and contaminants in mixed-use buildings and around special use areas. Examples of special use areas include attached parking garages, loading docks, print shops, smoking lounges, janitorial closets, storage areas, and kitchens.

Improperly located vents, exhausts and air intakes: Check the outdoor air intakes to see whether they are located near contaminant sources (e.g., plumbing vents, exhaust outlets, dumpsters, loading docks, or other locations where vehicles idle).

Unsanitary mechanical rooms: See if the space containing the HVAC system is clean and dry. Examples of problems include: cleaning or other maintenance supplies stored in mechanical room; dust and dirt buildup on floors and equipment; moisture in mechanical room because of inadequate insulation, lack of conditioned air, or failure to provide for air movement. Unsanitary conditions in the mechanical room are particularly a problem if unducted return air is dumped into and circulated through the mechanical room.

PRODUCTS OF COLLECTING DETAILED INFORMATION

- an inventory of HVAC system components that need to be repaired, adjusted, or replaced
- a current record of control settings and operating schedules
- a floor plan of the building showing airflow directions or pressure differentials around areas intended to run positive or negative (e.g., special use areas)
- an inventory of pollutant sources and their locations
- Material Safety Data Sheets for products used or stored within the building
- a record of usage for each zone or room, including the source of outside air and the presence of local exhaust (if any)



Occupants or staff sometimes open ceiling tiles into return plenums when attempting to eliminate odors. Building managers should be alert to such signs of occupant dissatisfaction in order to remedy the original problem and prevent additional problems, such as the short-circuiting of supply air.

Collect Detailed Information

The collection of detailed information for the IAQ profile can be handled as time is available. Areas that have been identified as presenting potential IAQ problems should be given the highest priority. You may want to review *Section 2* for background information on the factors that contribute to indoor air quality.

Inspect HVAC system condition and operation

Use your current maintenance records in combination with one or both of the **HVAC Checklists** to inspect HVAC

Sample Form

HVAC Checklist — Short Form

Mechanical Room

- Clean and dry? ______

  (describe items in need of attention) ______

- Stored refuse or chemicals? ______

Mechanical Equipment

- Preventative maintenance (PM) plan in use? ______

Control System Type ______

- System operation ______

Sample Form

Pollutant Pathway Record For IAQ Profile

Building Area (zone, room)	Use	Intended Pressure		Needs Attention? (Y/N)	Comments
		Positive (+)	Negative (-)		

SEE COMPLETE FORMS PAGES 97 AND 81

equipment and make sure that it is in good operating condition. A portion of the **HVAC Checklist - Short Form** is shown on this page, with the entire form reproduced in Tab V. The **HVAC Checklist - Long Form** (also reproduced in Tab V) is recommended where a more detailed examination is needed. You may want to create a new form incorporating elements from your existing inspection forms.

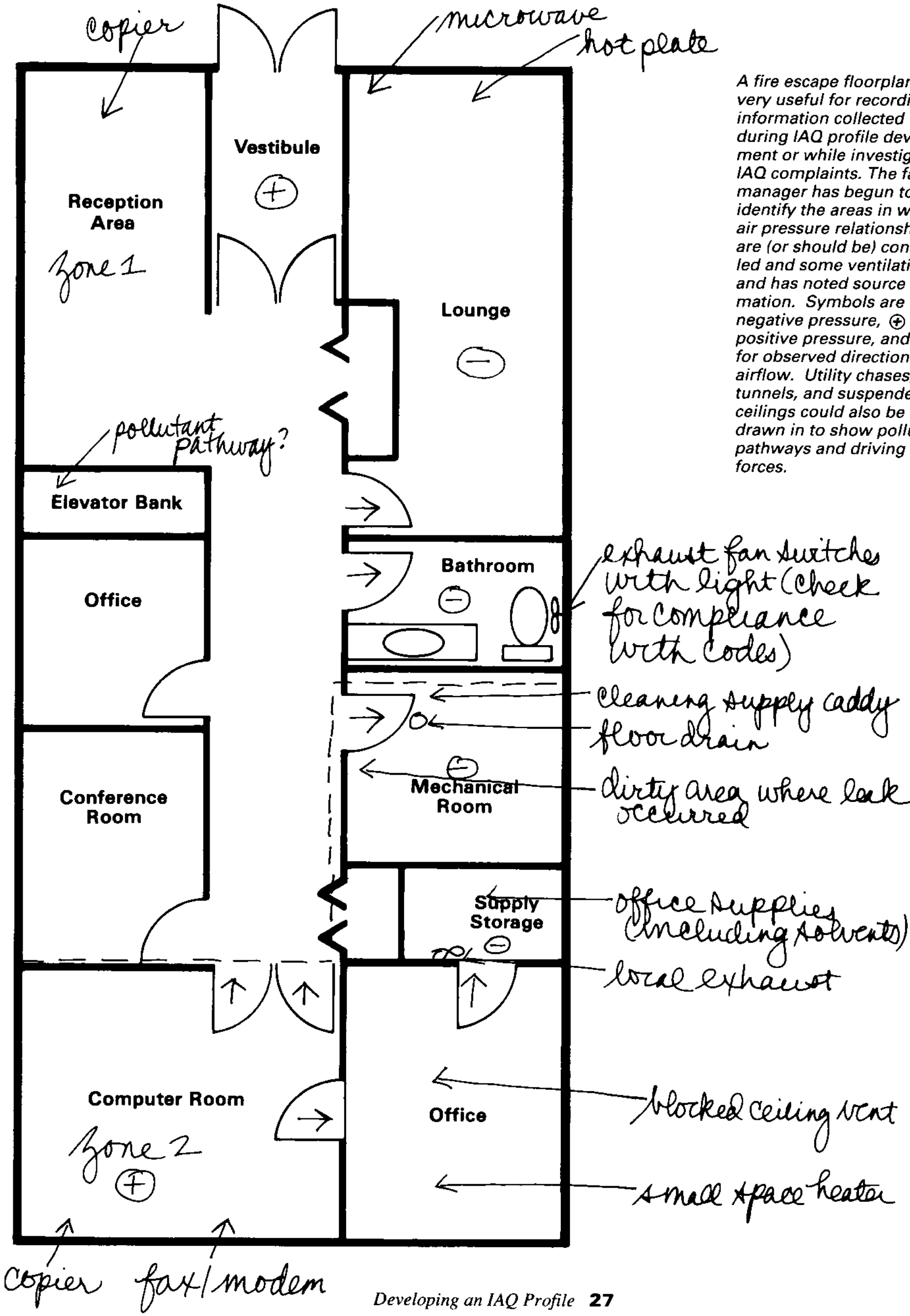
Identify items of equipment that need to be repaired, adjusted, or replaced. Record control settings and operating schedules for HVAC equipment for comparison to occupancy schedules and current uses of space.

Inventory pollutant pathways

Using the sketch plan of the building that was begun during the walkthrough inspection, indicate architectural connections (e.g., chases) and mechanical connections (e.g., ductwork, temperature control zones). Observe and record airflow between spaces intended to run positive or negative and the areas that surround them (including airflow between perimeter rooms and outdoors). Note that hidden pathways such as chases may travel both vertically and horizontally and transport pollutants over long distances. Record the results on the **Pollutant Pathway Record for IAQ Profiles,** the sketch plan, or both. The form is shown at the left (and in Tab V), and a sample sketch plan is shown on the opposite page.

Inventory pollutant sources

Use the **Pollutant and Source Inventory** (shown in part on page 28 and reproduced in full in Tab V) to record potential pollutant sources in the building. As you fill out the inventory form, note the locations of major sources. Major sources such as large items of equipment can be recorded on the floor plan. The **Chemical Inventory Form** (shown on page 28 and reproduced in Tab V) can be used to record the names and locations of chemicals or hazardous substances used or stored within



A fire escape floorplan is very useful for recording information collected during IAQ profile development or while investigating IAQ complaints. The facility manager has begun to identify the areas in which air pressure relationships are (or should be) controlled and some ventilation and has noted source information. Symbols are ⊖ for negative pressure, ⊕ for positive pressure, and ← for observed direction of airflow. Utility chases, tunnels, and suspended ceilings could also be drawn in to show pollutant pathways and driving forces.

Sample Form
Pollutant and Source Inventory Form

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment.

Source Category	Checked	Needs Attention	Location	Comments
SOURCES OUTSIDE THE BUILDING				
Contaminated Ambient Air				
Pollen, dust				
Industrial contaminants				
General vehicular contaminants				

Sample Form
Chemical Inventory Form

The inventory should include chemicals stored or used in the building for cleaning, maintenance, operations, and pest control. If you have an MSDS (Material Safety Data Sheet) for the chemical, put a check mark in the right-hand column. If not, ask the chemical supplier to provide the MSDS, if one is available.

Date	Chemical/ Brand Name	Use	Storage Location(s)	MSDS on File?

SEE COMPLETE FORMS PAGES 119 AND 127

the building, such as those that may be contained in cleaning materials, biocides, paints, caulks, and adhesives. Ask your suppliers to provide you with Material Safety Data Sheets.

You may be unaware of the potential hazards of some materials that are commonly used in public and commercial buildings. For example:

- In 1990, EPA eliminated the sale of mercury-containing interior latex paint. (Enamel paints do not contain mercury.) People are urged not to use exterior latex paint indoors, as it may contain mercury. If you have paint in storage that may have been manufactured before August 20, 1990, you may contact the manufacturer, the National Pesticide Telecommunication Network (1-800-858-7378), or your State Health Department for guidance.
- In 1990, EPA banned the use of hexavalent chromium chemicals in cooling towers, because the chemicals have been shown to be carcinogenic.
- Heating system steam should not be used in the HVAC humidification system, as it may contain potentially harmful chemicals such as corrosion inhibitors.

Collect information on building occupancy

The **Zone/Room Record** shown on the following page (and also reproduced in Tab V) can be used during IAQ profile development to maintain an up-to-date record of the way each area of the building is used, its source of outdoor air, and whether or not it is equipped with local exhaust. If underventilation is suspected, the form can be used to estimate ventilation rates in cubic feet per minute per person or per square foot floor area, for comparison to guidelines such as design documents, applicable building codes, or the recommendations of ASHRAE 62-1989 (see the table that is reproduced in *Appendix B*).

Sample Form

Zone/Room Record

This form is to be used differently depending on whether the goal is to prevent or diagnose IAQ problems. During development of a profile, this form should be used to record more general information about the entire building; during an investigation, the form should be used to record more detailed information about the complaint area and areas surrounding the complaint area or connected to it by pathways.

PROFILE AND DIAGNOSIS INFORMATION					DIAGNOSIS INFORMATION ONLY		
Building Area (Zone/Room)	Use**	Source of Outdoor Air*	Mechanical Exhaust? (Write “No” or estimate cfm airflow)	Comments	Peak Number of Occupants or Sq. Ft. Floor Area**	Total Air Supplied (in cfm)***	Outdoor Air Supplied per Person or per 150 sq. Ft. Area****

SEE COMPLETE FORM PAGE 177

Underventilation problems can occur even in areas where ventilation rates apparently meet ASHRAE guidelines; proper distribution and mixing of supply air with room air are also essential for good ventilation.

If the information collected as you develop the IAQ profile indicates that you have one or more IAQ problems, *Sections 6-8* provide guidance to help you deal with them. If you need to prioritize these problems, consider the apparent seriousness of their consequences. For example, combustion gas odors demand a more rapid respons than thermostats that are out of calibration.

Managing Buildings for Good IAQ

5

The relationships among building owners, management, staff, and occupants are an important factor in decisions that affect indoor air quality. The objectives of the major players in these relationships may be very different. Occupants want the building to be pleasant, safe, and attractive; if they are paying tenants, they also want to get the maximum use out of the space they rent for the least cost. Building owners and management want to maintain a reputation for providing quality property at reasonable cost, but also need to derive a profit. Facility staff are often caught in the middle, trying to control operating and maintenance costs while still keeping occupants satisfied.

Regardless of the points on which they may disagree, building occupants, staff, and management share the goal of providing a healthy indoor environment. Recognition of this common goal may help avoid conflict when discussing IAQ-related policies.

Any IAQ management system will be successful only if it is organized to fit your specific building. It would not be appropriate for this document to prescribe any single approach. However, the skills associated with IAQ management activities will be identified to help building management decide who will be best able to carry them out. Education and training programs for staff and building occupants should be provided to ensure that new procedures are understood and adopted.

Managing a building for good indoor air quality involves reviewing and amending current practice (and establishing new procedures, if necessary) to:

Operate and maintain HVAC equipment

- keep all equipment and controls in proper working order
- keep interior of equipment and ductwork clean and dry

Oversee activities of staff, tenants, contractors, and other building occupants that impact indoor air quality

- smoking
- housekeeping
- building maintenance
- shipping and receiving
- pest control
- food preparation and other special uses

Maintain communications with occupants so that management will be informed of complaints about the indoor environment in a timely way

- identify building management and staff with IAQ responsibilities
- use health and safety committees

Educate staff, occupants, and contractors about their responsibilities in relation to indoor air quality

- staff training
- lease arrangements
- contracts

Identify aspects of planned projects that could affect indoor air quality and manage projects so that good air quality is maintained

- redecorating, renovation, or remodeling
- relocation of personnel or functions within the building
- new construction

DEVELOPING AN IAQ MANAGEMENT PLAN

The chart on page 32 shows the elements of an IAQ management plan. Development of the management plan involves reviewing and revising staff responsibilities so that IAQ considerations become incorporated into routine procedures.

IAQ management systems will only be successful if they are organized to fit your specific building.

Organizations may assign responsibility for operations, recordkeeping, purchasing, communications, planning, and policy-making in many different ways. However, the key elements of good IAQ management remain the same:

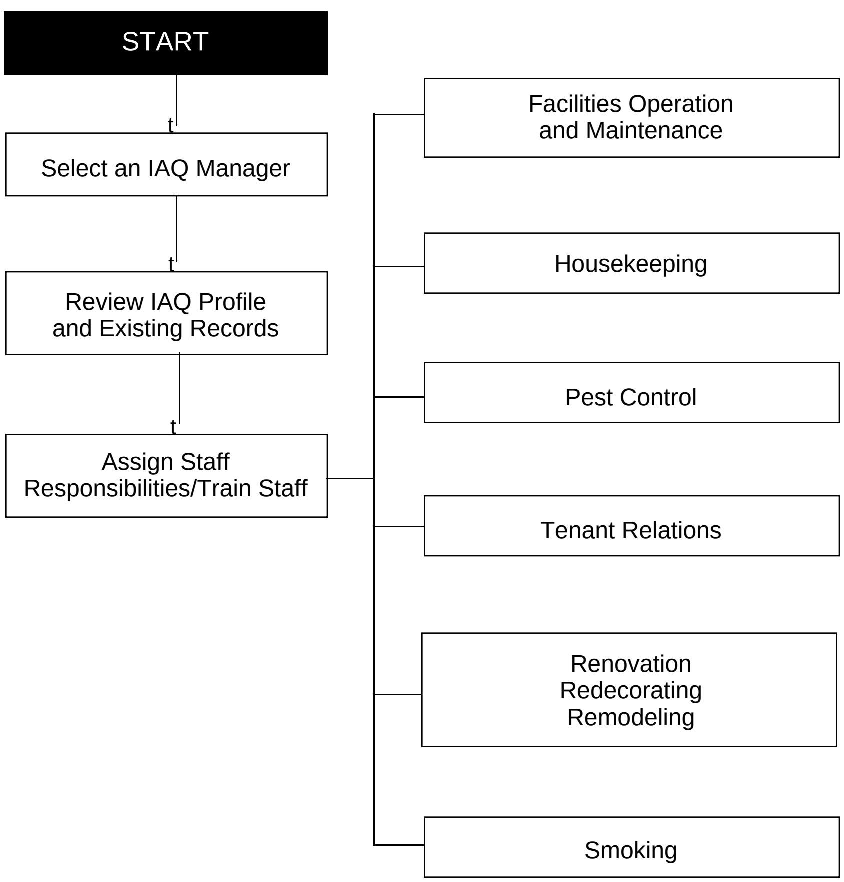
Reach an understanding of the fundamental influences that affect indoor air quality in your building by:

- becoming familiar with literature on IAQ
- keeping abreast of new information

Select an IAQ manager with:

- clearly defined responsibilities
- adequate authority and resources

FIGURE 5-1: Developing an IAQ Management Plan



Use the IAQ profile and other available information to:

- evaluate the design, operation, and usage of the building
- identify potential IAQ problem locations
- identify staff and contractors whose activities affect indoor air quality

Review and revise staff responsibilities to ensure that responsibilities that may affect indoor air quality are clearly assigned. In addition, establish lines of communication for sharing information pertaining to:

- equipment in need of repair or replacement
- plans to remodel, renovate, or redecorate
- new uses of building space or increases in occupant population
- installation of new equipment

Review standard procedures and make necessary revisions to promote good indoor air quality, such as:

- terms of contracts (e.g., pest control, leases)
- scheduling of activities that produce dust, emissions, odors
- scheduling of equipment operation, inspection, and maintenance
- specifications for supplies (e.g., cleaning products, construction materials, furnishings)
- policy regarding tobacco smoking within the building

Review the existing recordkeeping system and make necessary revisions to:

- establish a system for logging IAQ-related complaints
- obtain Material Safety Data Sheets for hazardous materials used and stored in the building

Educate building staff, occupants, and contractors about their influence on indoor air quality by:

- establishing a health and safety committee
- instituting training programs as needed

IAQ problems may occur even in buildings whose owners and managers conscientiously apply the best available information to avoid such problems. Those who can demonstrate their ongoing efforts to provide a safe indoor environment are in a strong legal and ethical position if problems do arise.

Select an IAQ Manager

IAQ management will be facilitated if one individual is given overall responsibility for IAQ. Whether or not this person is given the title of "IAQ Manager," he or she should have a good understanding of the building's structure and function and should be able to communicate with tenants, facility personnel, and building owners or their representatives about IAQ issues.

The IAQ manager's ongoing responsibilities might include:

- developing the IAQ profile
- overseeing the adoption of new procedures
- establishing a system for communicating with occupants about IAQ issues
- coordinating staff efforts that affect indoor air quality, and making sure that staff have the information (e.g., operating manuals, training) and authority to carry out their responsibilities
- reviewing all major projects in the building for their IAQ implications
- reviewing contracts and negotiating with contractors (e.g., cleaning services, pest control contractors) whose routine activities in the building could create IAQ problems
- periodically inspecting the building for indicators of IAQ problems
- managing IAQ-related records
- responding to complaints or observations regarding potential IAQ problems
- conducting an initial walkthrough investigation of any IAQ complaints

PRODUCTS OF THE REVIEW OF THE IAQ PROFILE AND OTHER EXISTING RECORDS

- a priority list of locations and activities within the building that will require special attention in order to prevent indoor air quality problems
- a list of staff and contractors whose responsibilities need to be included in the IAQ management plan

Review IAQ Profile and Other Existing Records

If the IAQ manager was not actively involved in developing the IAQ profile, one of the first tasks will be to review the profile carefully. The manager can start by also identifying building locations with a potential for IAQ problems, staff and contractors whose activities impact indoor air quality, and other building occupants whose activities impact indoor air quality.

In addition to information from the IAQ profile, it may be helpful to review lease forms and other contractual agreements for an understanding of the respective legal responsibilities of the building management, tenants, and contractors. Incorporation of IAQ concerns into legal documents helps to ensure the use of proper materials and procedures by contractors and can help to limit the load placed on ventilation equipment by occupant activities.

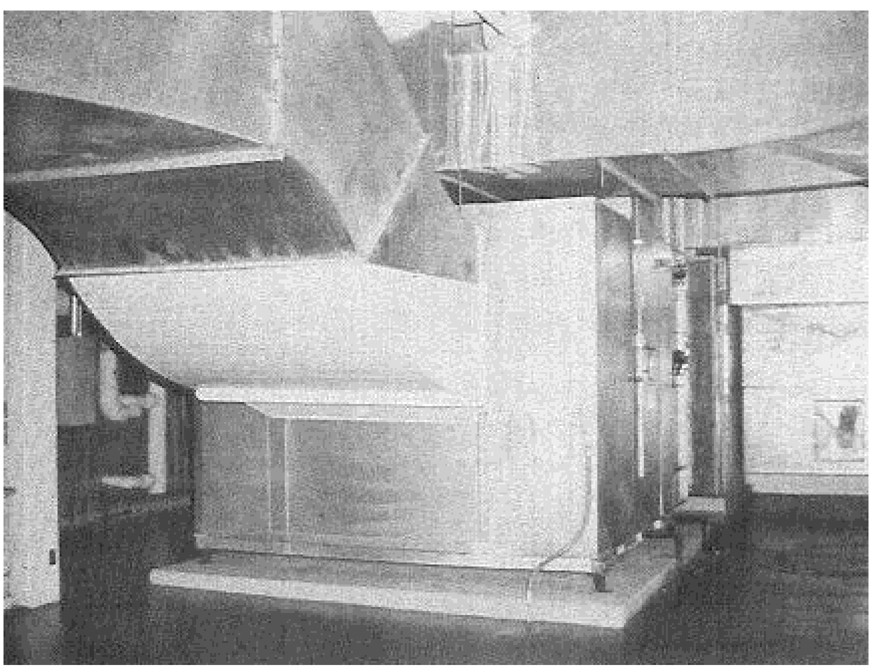
IAQ management will be facilitated if one individual is given overall responsibility for IAQ.

Assign Responsibilities/ Train Staff

The assignment of responsibilities varies widely between organizations, depending upon the routine activities to be carried out and the capabilities of the available personnel. It would not be appropriate for this document to suggest how IAQ-related responsibilities should be allocated in your organization. For example, issues of access in buildings with tenant-occupied space highlight the need for cooperation between building managers and the tenants' office managers. The building staff may be limited in its access to tenant spaces and tenants may not have access to building operations areas such as mechanical rooms, yet both tenants and building management have responsibilities for maintaining good indoor air quality.

Facility personnel are not generally trained to think about IAQ issues as they go about their work. Even though building staff may be observing events and conditions that would indicate potential problems to an experienced IAQ investigator, the staff member's attention may be directed elsewhere. As new practices are introduced to prevent indoor air quality problems, an organized system of recordkeeping will help those practices to become part of routine operations and to "flag" decisions that could affect IAQ (e.g., renovations, new tenants). The best results can be achieved by taking time to think about the established channels of communication within your organization, so that new forms can be integrated into decisionmaking with minimum disruption of normal procedures.

A clean mechanical room, free of tracked-in dirt and stored chemicals, is an important element in the prevention of indoor air quality problems. Airborne contaminants in the mechanical room can be drawn into ductwork through return air openings or unsealed seams in return ducts and circulated throughout the building.



Using information from the IAQ profile, the IAQ manager should work with staff and contractors to ensure that building operations and planning processes incorporate a concern for indoor air quality. New procedures, recordkeeping requirements, or staff training programs may be needed. (Growing interest in IAQ is stimulating government agencies and private sector organizations to develop training programs. See *Appendix G* for additional information.) The flow of information between the IAQ manager and staff, occupants, and contractors is particularly important. Good indoor air quality requires prompt attention to changing conditions that could cause IAQ problems, such as installation of new equipment or furnishings, increases in occupant population, or new uses of rooms.

Facility Operation and Maintenance

Indoor air quality can be affected both by the quality of maintenance and by the materials and procedures used in operating and maintaining the building components including the HVAC system.

Facility staff who are familiar with building systems in general and with the features of their building in particular are an important resource in preventing and resolving indoor air quality problems. Facility personnel can best respond to indoor air quality concerns if they understand how their activities affect indoor air quality. It may be necessary to change existing practices or introduce new procedures in relation to:

Equipment operating schedules: Confirm that the timing of occupied and unoccupied cycles is compatible with actual occupied periods, and that the building is flushed by the ventilation system before occupants arrive. ASHRAE 62-1989 provides guidance on lead and lag times for HVAC equipment. In hot, humid climates, ventilation may be needed during long unoccupied periods to prevent mold growth.

Control of odors and contaminants: Maintain appropriate pressure relationships between building usage areas. Avoid recirculating air from areas that are strong sources of contaminants (e.g., smoking lounges, chemical storage areas, beauty salons). Provide adequate local exhaust for activities that produce odors, dust, or contaminants, or confine those activities to locations that are maintained under negative pressure (relative to adjacent areas). For example, loading docks are a frequent source of combustion odors. Maintain the rooms surrounding loading docks under positive pressure to prevent vehicle exhaust from being drawn into the building. Make sure that paints, solvents, and other chemicals are stored and handled properly, with adequate (direct exhaust) ventilation provided. If local filter traps and adsorbents are used, they require regular maintenance. Have vendors provide Material Safety Data Sheets (MSDSs).

Ventilation quantities: Compare outdoor air quantities to the building design goal and local and State building codes and make adjustments as necessary. It is also informative to see how your ventilation rate compares to ASHRAE 62-1989, because that guideline was developed with the goal of preventing IAQ problems. (*Note*: Increasing ventilation quantities to meet ASHRAE guidelines may exceed the capacity of HVAC equipment to condition the air.)

HVAC equipment maintenance schedules: Inspect all equipment regularly (per recommended maintenance schedule) to ensure that it is in good condition and is operating as designed (i.e., as close to the design setpoints for controls as possible). Most equipment manufacturers provide recommended maintenance schedules for their products. Components that are exposed to water (e.g., drainage pans, coils, cooling towers, and humidifiers) require scrupulous maintenance to prevent microbiological growth and the entry of undesired microbiologicals or chemicals into the indoor airstream.

HVAC inspections: Modify the **HVAC Checklists** (reproduced in Tab V) as necessary so that they are appropriate for inspection of the specific equipment in your building. Be thorough in conducting these inspections. Items such as small exhaust fans may operate independently from the rest of the HVAC system and are often ignored during inspections. As equipment is added, removed, or replaced, document any changes in function, capacity, or operating schedule for future reference. It may also be helpful to store equipment manuals and records of equipment operation and maintenance in the same location as records of occupant complaints for easy comparison if IAQ problems arise.

Be thorough in conducting HVAC inspections. Items such as small exhaust fans may operate independently from the rest of the system and are often ignored during inspections.

Building maintenance schedules: Try to schedule maintenance activities that interfere with HVAC operation or produce odors and emissions (e.g., painting, roofing operations) so that they occur when the building is unoccupied. Inform occupants when such activities are scheduled and, if possible, use local ventilation to ensure that dust and odors are confined to the work area.

Purchasing: Review the general information provided by MSDS and request information from suppliers about the chemical emissions of materials being considered for purchase.

Note: At present there is no general system for certifying or labeling low-emission products nor is there a standard procedure for building managers to use in gathering emissions data on products they are considering for purchase. Limited information on some materials such as

PREVENTIVE MAINTENANCE

An HVAC system requires adequate preventive maintenance (PM) and prompt attention to repairs in order to operate correctly and provide suitable comfort conditions and good indoor air quality. The HVAC system operator(s) must have an adequate understanding of the overall system design, its intended function, and its limitations. The preventive maintenance program must be properly budgeted and implemented, not merely planned on paper.

A well-implemented PM plan will improve the functioning of the mechanical systems and usually save money when evaluated on a life-cycle basis. However, in some buildings, because of budgetary constraints, maintenance is put off until breakdowns occur or complaints arise, following the “if it isn’t broken, don’t fix it” philosophy. This type of program represents a false economy and often increases the eventual cost of repairs.

Poor filter maintenance is a common example of this phenomenon. Filters that are not changed regularly can become a bed for fungal growth, sometimes allowing particles or microorganisms to be distributed within the building. When filters become clogged, the fans use more energy to operate and move less air. If the filters are an inexpensive, low-efficiency type that becomes clogged and then “blows out,” the coils then accumulate dirt, causing another increase in energy consumption. Poor air filter efficiency and poor maintenance may cause dirt to build up in ducts and become contaminated with molds, possibly requiring an expensive duct cleaning operation.

General elements of a PM plan include:

- periodic inspection, cleaning, and service as warranted
- adjustment and calibration of control system components
- maintenance equipment and replacement parts that are of good quality and properly selected for the intended function

Critical HVAC system components that require PM in order to maintain comfort and deliver adequate ventilation air include:

- outdoor air intake opening
- damper controls
- air filters
- drip pans
- cooling and heating coils
- fan belts
- humidification equipment and controls
- distribution systems
- exhaust fans

Some private sector organizations have developed guidance on preventive maintenance. (See discussion in Guidelines of Care Developed by Trade Associations on page 43.)

pressed-wood products is available, and more may be expected in the future. Public and private sector organizations are working to develop product testing procedures for acceptance by such organizations as the American Society for Testing and Materials (ASTM).

Preventive maintenance management: Maintenance “indicators” are available to help facility staff determine when routine maintenance is required. For example, air filters are often neglected (sometimes due to reasons such as difficult access) and fail to receive maintenance at proper intervals. Installation of an inexpensive manometer, an instrument used to monitor the pressure loss across a filter bank, can give an immediate indication of filter condition without having to open the unit to visually observe the actual filter.

Computerized systems are available that can prompt your staff to carry out maintenance activities at the proper intervals. Some of these programs can be connected to building equipment so that a signal is transmitted to your staff if a piece of equipment malfunctions. Individual areas can be monitored for temperature, air movement, humidity, and carbon dioxide, and new sensors are constantly entering the market. These sensors can be programmed to record data and to control multiple elements of the HVAC system.

Housekeeping

Indoor air quality complaints can arise from inadequate housekeeping that fails to remove dust and other dirt. On the other hand, cleaning materials themselves produce odors and emit a variety of chemicals.

As they work throughout your building, cleaning staff or contractors may be the first to recognize and respond to potential IAQ problems. Educate them about topics such as the following:

Cleaning schedules: Consider how cleaning activities are scheduled. Managers may want to schedule the use of some cleaning agents that introduce strong odors or contaminants during unoccupied periods. However, make sure that fumes from cleaning products are eliminated before air handling systems switch to their "unoccupied" cycles.

Purchasing: Become more familiar with the chemicals in cleaning and maintenance products and their potential toxicity. Select the safest available materials that can achieve your purpose. Review the information provided by product labels and Material Safety Data Sheets. Request information from suppliers about the chemical emissions of products being considered for purchase.

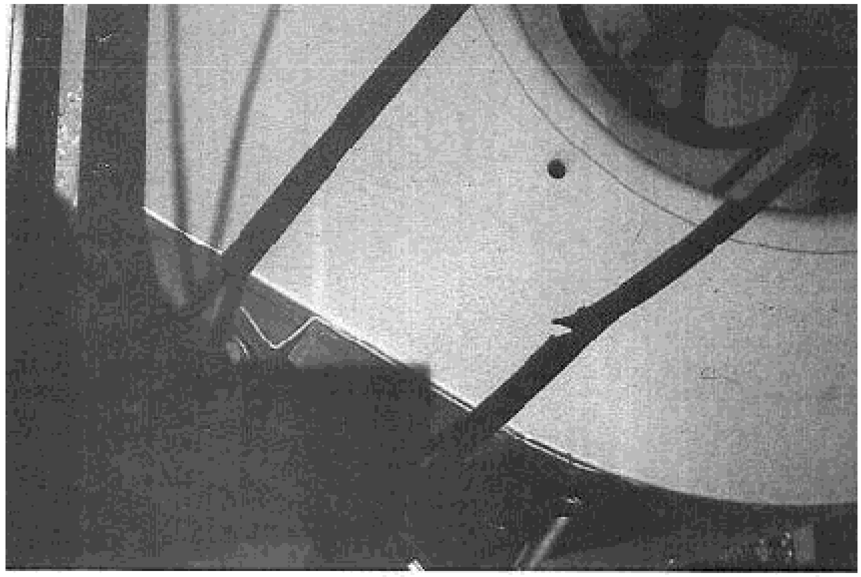
Material handling and storage: Review the use of cleaning materials to ensure proper use and storage.

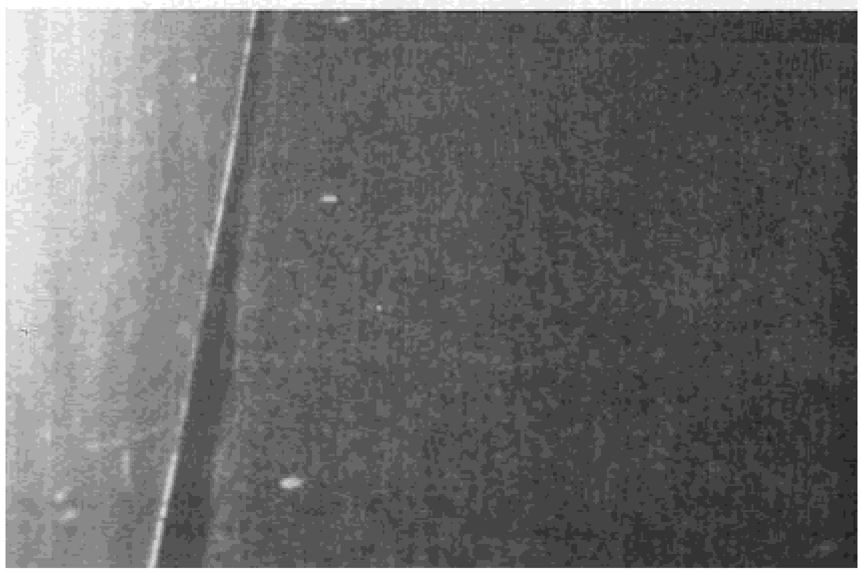
Trash disposal: Follow proper trash disposal procedures. If there is a restaurant in the building, require daily pick-up of perishable refuse. Ensure that the containers are covered, pest control is effective, and that the trash collection area is cleaned at least daily.

Shipping and Receiving

Shipping and receiving areas can create indoor air quality problems regardless of the types of materials being handled. Vehicle exhaust fumes can be minimized by prohibiting idling at the loading dock. This is particularly important if the loading dock is located upwind of outdoor air intake vents. You can also reduce drafts and pollutant entry by pressurizing interior spaces (e.g., corridors) and by keeping doors closed when they are not in use.

A good preventive maintenance program can help a facility manager identify and correct problems before they occur. If this fan belt breaks, the area served by the air handling unit may be without ventilation. If it is slipping, it is already reducing the airflow.





A termiticide misapplication resulted in an indoor air quality problem in this school. Detectable levels of chlordane were found in both wipe (surface) and air samples near the injection holes drilled into the ground floor. Note the small white circles near the wall. (Under an agreement with EPA, manufacturers have withdrawn chlordane from sale.) Proper application methods are important for all pesticides.

INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) is a coordinated approach to pest control intended to prevent unacceptable levels of pests, while causing the least possible hazard to people, property, and the environment and using the most cost-effective means. IPM uses a combination of tactics, including sanitation, monitoring, habitat modification, and the judicious application of pesticides when absolutely necessary.

IPM methods include:

- improved sanitation (e.g., removing food from desks, cleaning)
- inspection and monitoring of pest population sites
- managing waste (e.g., keeping refuse in tight containers, locating waste containers away from building if possible)
- maintaining structures (e.g., fixing leaking pipes promptly, sealing cracks)
- adding physical barriers to pest entry and movement (e.g., screens for chimneys, doors, and windows; air curtains)
- modifying habitats (e.g., removing clutter, relocating outside light fixtures away from doors)
- using traps (e.g., light traps, snap traps, and glue boards)
- using pesticides judiciously

An efficient IPM program will integrate pest management planning with preventive maintenance, housekeeping practices, landscaping, occupant education, and staff training.

Pest Control

Pest control activities that depend upon the use of pesticides involve the storage, handling, and application of materials that can have serious health effects. Common construction, maintenance practices, and occupant activities provide pests with air, moisture, food, warmth, and shelter. Caulking or plastering cracks, crevices, or holes to prevent harborage behind walls can often be more effective than pesticide application at reducing pest populations to a practical minimum.

Integrated Pest Management (IPM) is a low-cost approach to pest control based upon knowledge of the biology and behavior of pests. Adoption of an IPM program can significantly reduce the need for pesticides by eliminating conditions that provide attractive habitats for pests.

If an outside contractor is used for pest control, it is advisable to review the terms of the contract and include IPM principles where possible. The following items deserve particular attention.

Pest control schedule: Schedule pesticide applications for unoccupied periods, if possible, so that the affected area can be flushed with ventilation air before occupants return. Pesticides should only be applied in targeted locations, with minimum treatment of exposed surfaces. They should be used in strict conformance with manufacturers' instructions and EPA labels. General periodic spraying may not be necessary. If occupants are to be present, they should be notified prior to the pesticide application. Particularly susceptible individuals could develop serious illness even though they are only minimally exposed.

Materials selection, handling, and storage: Select pesticides that are species specific and attempt to minimize toxicity for humans and non-target species. Ask contractors or vendors to provide EPA labels and MSDSs. Make sure that pesticides are stored and handled properly consistent with their EPA labels.

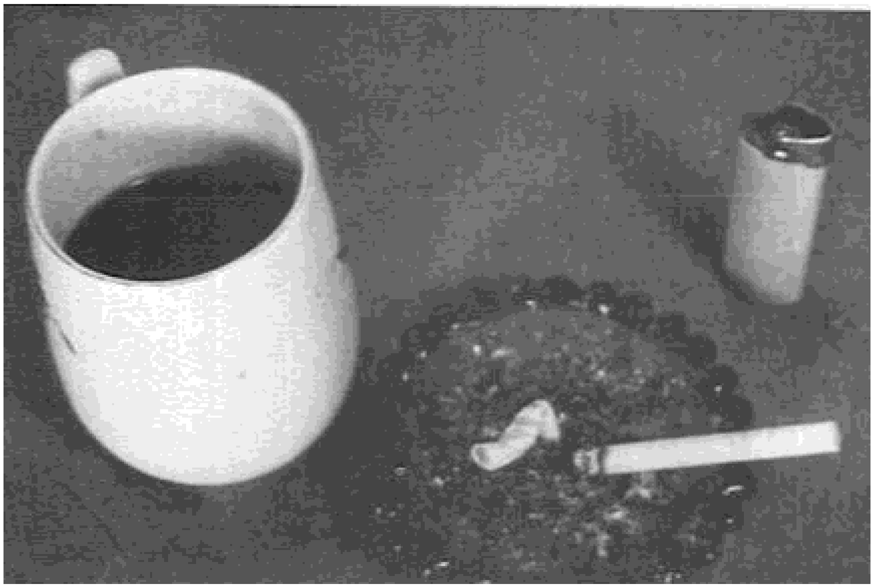
Ventilation of areas where pesticides are applied: If only limited areas of the building are being treated, adjust the HVAC system so that it does not distribute contaminated air throughout the rest of the building. Consider using temporary exhaust systems to remove contaminants during the work. It may be necessary to modify HVAC system operation during and after pest control activities (e.g., running air handling units on 100% outdoor air for some period of time or running the system for several complete air exchanges before occupants re-enter the treated space).

MATERIAL SAFETY DATA SHEETS

Under OSHA regulations, responsible parties are required to document information on potentially hazardous products. These Material Safety Data Sheets (MSDSs) may be of limited help in identifying some products that may pose IAQ concerns. However, professional judgment and collection of additional information may be necessary in order to make full use of the MSDS. The following table summarizes some of the issues to keep in mind when deciding whether information from MSDSs is applicable to emission sources and exposures of concern in a building.

Item	Possible Uses	Comments
Substances Covered	■ MSDSs *may* identify significant airborne contaminants	■ MSDSs may not be available onsite for many products ■ some components are listed as proprietary and are not disclosed ■ MSDSs do not always highlight products most likely to be airborne ■ contaminant byproducts inadvertently formed during manufacture won't always be listed
Personal Protection/ First Aid	■ may suggest precautions for conducting source inspection	■ usually relates only to high-level, worst-case exposures in general industry
Health Effects	■ *generally* presents types of health effects that may be expected primarily at high level (e.g., industrial) exposures	■ symptoms listed may not occur at low-level concentrations found in indoor air ■ MSDSs may not include more subtle IAQ aspects such as nuisance factors and sensitivity to mixtures
Physical Data	■ odor description may help identify sources ■ volatility *may* suggest which products are likely to be airborne ■ contaminants to expect in event of a fire or decomposition may be listed ■ reactivity data may suggest potential problems with storage or use	■ reference material on how to use physical data information to predict IAQ impacts may be scarce
Control Measures	■ identifies proper storage and packaging procedures ■ identifies steps for cleanup of gross spills	■ many office chemicals are kept in much smaller amounts than found in industrial settings ■ spill cleanup may not eliminate airborne contamination ■ does not specify routine emission controls

A reasonable effort should be made to collect available MSDSs during IAQ profile development. Care should be taken to consider information that is relevant to IAQ concerns. Other important indicators of how a particular product may affect IAQ are available from direct odor and dust observations, a review of work practices and interviews with operators and occupants. The manufacturer is a good source of follow-up information on a given product (phone number should be included on each MSDS).



It is important for building occupants to understand that their activities can create indoor air quality problems. Smoking releases both carcinogenic and irritating substances into the air.

Occupant Relations

Managing occupant relations to prevent IAQ problems involves: allocating space and monitoring the use of building areas to isolate odor- and contaminant-producing activities and avoid re-entrainment; establishing a communication strategy that is responsive to complaints and provides tenants with information about their role in preventing indoor air quality problems; and modifying employee manuals or lease agreements as necessary to clarify the responsibilities of occupants and building management. A health and safety committee or joint tenant-management IAQ task force that represents all of the major interest groups in the building can be very helpful in disseminating information and fostering a cooperative approach to IAQ management. See *Section 3* for a discussion of these points.

Renovation, Redecorating, and Remodeling

Renovation, redecorating, and remodeling activities can create indoor air problems by producing dust, odors, microbiologicals and their spores, and emissions. It is difficult to prevent IAQ problems if some building areas are undergoing renovation while adjoining areas continue normal operations.

Close monitoring of renovation, redecorating, and remodeling projects is recommended. The following suggestions may be helpful:

Working with professional consultants: Communicate your concern about preventing indoor air quality problems to the engineer, architect, interior designer, or other professionals involved in the project.

Product selection: Specify products and processes that minimize odors and emissions, while maintaining adequate safety and efficacy. Review the general information provided by the product labels and MSDSs. Request information from suppliers about the chemical emissions of products being considered for purchase.

Work schedules: Schedule activities that produce dust, odors, or emissions for unoccupied periods if possible.

Isolation of work areas: Block off return registers so that contaminants are not recirculated from the demolition/construction area into adjoining areas, and install temporary barriers to confine dust and noise. If possible, install temporary local exhaust to remove odors and contaminants, and check to confirm that the temporary ventilation system is operating as planned.

Installation of new furnishings: Ask suppliers to store new furnishings in a clean, dry, ventilated location so that volatile organic compounds will be emitted before installation. Minimize the use of adhesives during installation or specify low-emitting products. After new furnishings are installed, increase the ventilation rate to flush the area with outdoor air and dilute emissions.

Smoking

Although there are many potential sources of indoor air pollution, both research and field studies have shown that environmental tobacco smoke (ETS) is one of the most widespread and harmful indoor air pollutants. Environmental tobacco smoke is a combination of sidestream smoke from the burning end of the cigarette, pipe, or cigar and the exhaled mainstream smoke from the smoker. ETS contains over 4,000 chemicals; 43 of which are known animal or human carcinogens. Many other chemicals in ETS are tumor promoters, tumor initiators, co-carcinogens (i.e., chemicals that are able to cause cancer when combined with another substance), or cancer precursors (i.e., compounds that can make it easier to form other carcinogenic chemicals).

In 1986, *The Health Consequences of Involuntary Smoking: A Report of the Surgeon General on Environmental Tobacco Smoke* concluded that ETS was a cause of lung cancer in healthy non-smokers and that "the scientific case against involuntary smoking as a public health risk is more than sufficient to justify appropriate remedial action, and the goal of any remedial action must be to protect the non-smoker from environmental tobacco smoke." In the same year, the National Research Council of the National Academy of Sciences issued a report, *Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects,* which also concluded that passive smoking increases the risk of lung cancer in adults.

In June 1991, NIOSH issued a *Current Intelligence Bulletin (#54)* on ETS in the workplace that dealt with lung cancer and other health effects. In its *Bulletin*, NIOSH concluded that the weight of evidence is sufficient to conclude that ETS can cause lung cancer in non-smokers (i.e., those who inhale ETS). It recommended that the preferable method to protect non-smokers is the elimination of smoking indoors and that the alternative method is to require that smoking be permitted only in separately ventilated smoking areas. The NIOSH *Bulletin* emphasized that provision of such isolated areas should be viewed as an interim measure until ETS can be completely eliminated indoors.

PRODUCTS OF THE ASSIGNMENT OF RESPONSIBILITIES AND REVIEW OF TRAINING

- job descriptions and/or contracts, work procedures, and schedules revised to reflect indoor air quality concerns
- procedures for reviewing purchases of supplies, new projects, contracts, and policies in relation to indoor air quality
- smoking policy revisions, if necessary
- plans for educating occupants and training staff training in relation to indoor air quality

Smoking areas must be separately ventilated, negatively pressurized in relation to surrounding interior spaces, and supplied with much more ventilation than non-smoking areas. The NIOSH *Bulletin* also recommends that the air from the smoking area should be exhausted directly outdoors and not recirculated within the building or vented with the general exhaust for the building. ASHRAE Standard 62-1989 recommends that smoking areas be supplied with 60 cubic feet per minute (60 cfm) per occupant of outdoor air; the standard also recognized that using transfer air, which is pulled in from other parts of the building, to meet the standard is common practice.

Both EPA and NIOSH advise that building owners or facility managers considering the introduction of smoking restrictions should implement smoking cessation programs. In addition, employees and labor unions should be involved in the development of non-smoking policies in the workplace.

(Refer to *Appendix G* for citations on all the publications mentioned in this section. See especially NIOSH *Current Intelligence Bulletin (#54), Environmental Tobacco Smoke in the Workplace: Lung Cancer and Other Health Effects.* Additional resources on ETS, including an assessment of respiratory disorders in children and lung cancer risks in adults, and a guide to developing effective smoking policies, will be available from EPA early in 1992.)

According to a 1986 report of the Surgeon General, "the case against involuntary smoking is more than sufficient to justify appropriate remedial action to protect the non-smoker from environmental tobacco smoke."

Sample Form

Management Checklist

Item	Date Begun or Completed (as applicable)	Responsible Person (name, telephone)	Location ("NA" if the item is not applicable to this building)
IAQ PROFILE			
Collect and Review Existing Records			
HVAC design data, operating instructions and manuals			
HVAC maintenance and calibration records, testing and balancing reports			
Inventory of locations where occupancy, equipment, or building use has changed			
Inventory of complaint locations			
Conduct a Walkthrough Inspection of the Building			
List of responsible staff and/or contractors, evidence of training, and job descriptions			
Identification of areas where positive or negative pressure should be maintained			

SEE COMPLETE FORM PAGE 171

*The **IAQ Management Checklist** shown in part here and included in full within Tab V can be used to help confirm that you have accounted for the major factors that could cause IAQ problems in your building.*

GUIDELINES OF CARE DEVELOPED BY TRADE ASSOCIATIONS	The following associations have developed guidelines of care that may have a direct or indirect impact on indoor air quality. These standards are described below so that building management may become aware of them. Neither EPA nor NIOSH endorse these standards.
Air Conditioning Contractors of America (ACCA)	Technical Reference Bulletin Series. Indoor air quality is one of the topics covered in this series of technical bulletins on heating, ventilation and air conditioning (HVAC). Bulletins can be filed in the ACCA Technical Reference Notebook. The Air Side Design tab of the notebook includes bulletins devoted to indoor air quality control.
Air Conditioning and Refrigeration Institute (ARI)	Air Conditioning and Refrigeration Equipment General Maintenance Guidelines for Improving the Indoor Environment (1991). General maintenance requirements for heating ventilation, air conditioning,and refrigeration (HVACR) equipment. Specific equipment/component maintenance is given for the following: air cleaning systems; ducts; registers/diffusers and air terminals; dampers/economizers; drain pans; air handlers; humidifiers; package terminal units; and evaporator, condenser, hydronic and economizer coils. The guidelines do not supersede any maintenance instructions that are provided by the manufacturer. In addition, the Institute has issued an Indoor Air Quality Briefing Paper that addresses the interactions between HVACR equipment and the quality of indoor air.
Associated Air Balance Council (AABC)	National Standards for Testing and Balancing Heating,Ventilation, and Air Conditioning Systems (1989). Establishes a minimum set of field testing and balancing standards and provides comprehensive and current data on testing and balancing HVAC systems. Chapters receiving special attention include Cooling Tower Performance Tests, Sound Measurements, Vibration Measurements, Fume Hoods, and AABC General Specifications. The book contains a complete index to the technical data provided.
National Environmental Balancing Bureau (NEBB)	Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems (1991). A “how-to” set of procedural standards that provide systematic methods for testing, adjusting, and balancing (TAB) of HVAC systems. Includes sections on TAB instruments and calibration, report forms, sample specifications, and engineering tables and charts. A valuable innovation is the “Systems Ready to Balance” start-up checklist to help organize jobs systematically. Other features include: additional engineering data, condensed duct design tables/charts, hydronic design tables/charts, and pertinent HVAC equations in U.S. and metric units.
National Pest Control Association (NPCA)	Good Practice Statements. Periodically updated, officially approved and adopted by the Association’s Board of Directors, these “Good Practice Statements” are designed as guidelines for performing various services rather than standards of operation. In addition, the Association produces a self-study series for technicians that covers five areas of pest control, management manuals, an encyclopedia of structural pest control, a number of specific subject matter technical reference manuals, and a pamphlet series.
Sheet Metal and Air Conditioning Contractors’ National Association (SMACNA)	HVAC Duct Construction Standards — Metal and Flexible (1985). Primarily for commercial and institutional work, this set of construction standards is a collection of material from earlier editions of SMACNA’s low-pressure, high-pressure, flexible duct, and duct liner standards. In addition, SMACNA has published a manual entitled *Indoor Air Quality* that contains basic information on many aspects of indoor air quality and guidance on conducting building evaluations and indoor air quality audits. Other related SMACNA publications include *HVAC Duct Systems Inspection Guide*, *HVAC Systems—Testing, Adjusting and Balancing,* and *HVAC Air Duct Leakage Test Manual.*

RESOLVING IAQ PROBLEMS

Building Air Quality

Diagnosing IAQ Problems

6

The goal of the diagnostic building investigation is to identify and solve the indoor air quality complaint in a way that prevents it from recurring and that does not create other problems. This section describes a method for discovering the cause of the complaint and presents a "toolbox" of diagnostic activities to assist you in collecting information.

Just as a carpenter uses only the tools that are needed for any given job, an IAQ investigator should use only the investigative techniques that are needed. Many indoor air quality complaints can be resolved without using all of the diagnostic tools described in this chapter. For example, it may be easy to identify the source of cooking odors that are annoying nearby office workers and solve the problem by controlling pressure relationships (e.g., installing exhaust fans) in the food preparation area. Similarly, most mechanical or carpentry problems probably require only a few of the many tools you have available and are easily accomplished with in-house expertise.

The use of in-house personnel builds skills that will be helpful in minimizing and resolving future problems. On the other hand, some jobs may be best handled by contractors who have specialized knowledge and experience. In the same way, diagnosing some indoor air quality problems may require equipment and skills that are complex and unfamiliar. Your knowledge of your organization and building operations will help in selecting the right tools and deciding whether in-house personnel or outside professionals should be used in responding to the specific IAQ problem.

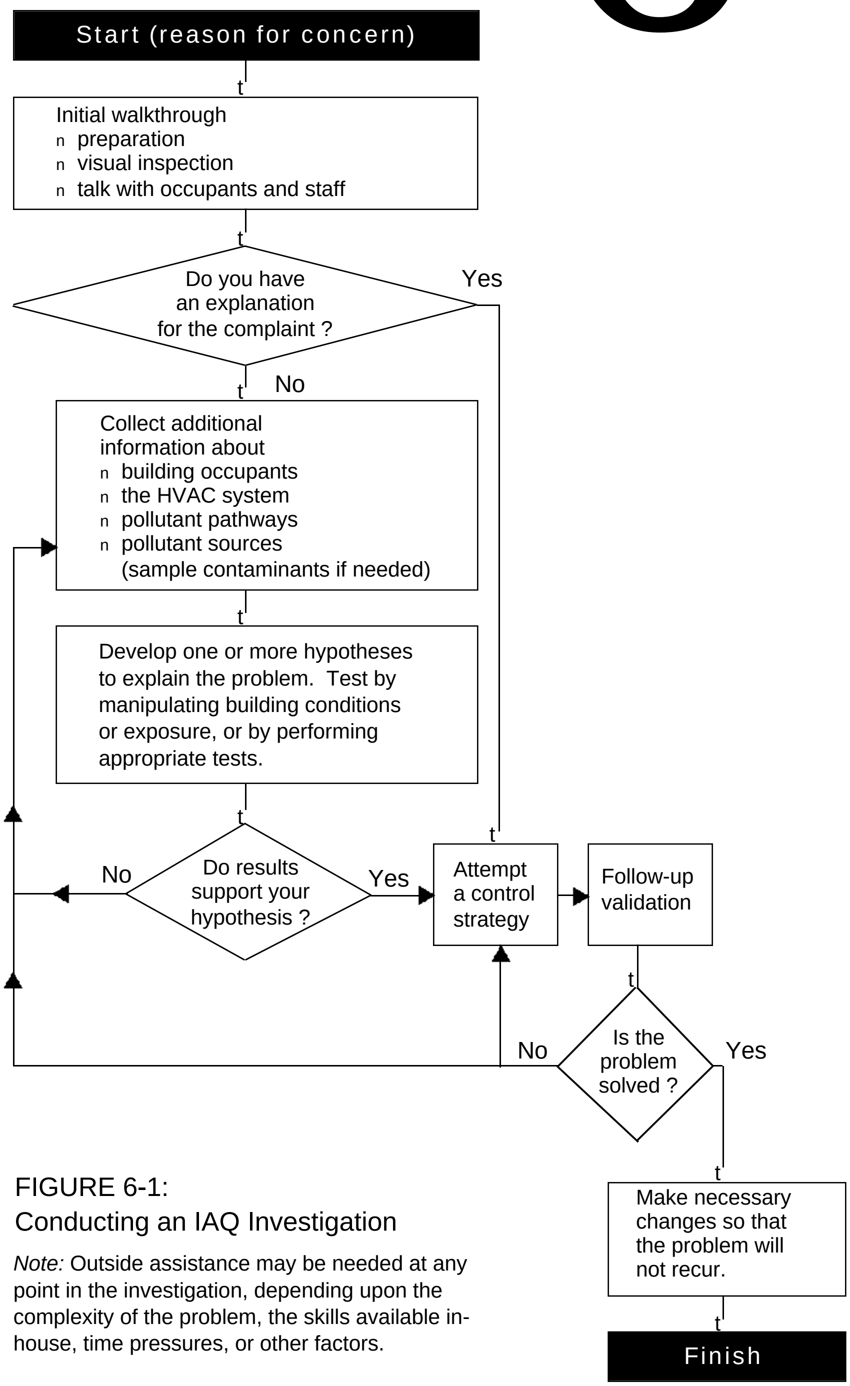


FIGURE 6-1:
Conducting an IAQ Investigation

Note: Outside assistance may be needed at any point in the investigation, depending upon the complexity of the problem, the skills available in-house, time pressures, or other factors.

The IAQ investigation is often a repetitive cycle of information-gathering, hypothesis formation, and hypothesis testing.

OVERVIEW: CONDUCTING AN IAQ INVESTIGATION

An IAQ investigation begins with one or more reasons for concern, such as occupant complaints. Some complaints can be resolved very simply (e.g., by asking a few common sense questions of occupants and facility staff during the walkthrough). At the other extreme, some problems could require detailed testing by an experienced IAQ professional. In this section "the investigator" refers to in-house staff responsible for conducting the IAQ investigation.

The flowchart on page 45 shows that the IAQ investigation is a cycle of information-gathering, hypothesis formation, and hypothesis testing. The goal of the investigation is to understand the IAQ problem well enough so that you can solve it. Many IAQ problems have more than one cause and may respond to (or require) several corrective actions.

Initial Walkthrough

An initial walkthrough of the problem area provides information about all four of the basic factors influencing indoor air quality (occupants, HVAC system, pollutant pathways, and contaminant sources). The initial walkthrough may provide enough information to resolve the problem. At the least, it will direct further investigation. For example, if the complaint concerns an odor from an easily-identified source (e.g., cooking odors from a kitchen), you may want to study pollutant pathways as a next step, rather than interviewing occupants about their patterns of discomfort.

Developing and Testing Hypotheses

As you develop an understanding of how the building functions, where pollutant sources are located, and how pollutants move within the building, you may think of many "hypotheses," potential explanations of the IAQ complaint. Building occupants and operating staff are often a good source of ideas about the causes of the problem. For example, they can describe changes in the building that may have occurred shortly before the IAQ problem was noticed (e.g., relocated partitions, new furniture or equipment).

Hypothesis development is a process of identifying and narrowing down possibilities by comparing them with your observations. **Whenever a hypothesis suggests itself, it is reasonable to pause and consider it.** Is the hypothesis consistent with the facts collected so far?

You may be able to test your hypothesis by modifying the HVAC system or attempting to control the potential source or pollutant pathway to see whether you can relieve the symptoms or other conditions in the building. If your hypothesis successfully predicts the results of your manipulations, then you may be ready to take corrective action. Sometimes it is difficult or impossible to manipulate the factors you think are causing the IAQ problem; in that case, you may be able to test the hypothesis by trying to predict how building conditions will change over time (e.g., in response to extreme outdoor temperatures).

Collecting Additional Information

If your hypothesis does not seem to be a good predictor of what is happening in the building, you probably need to collect more information about the occupants, HVAC system, pollutant pathways, or contaminant sources. Under some circumstances, detailed or sophisticated measurements of pollutant concentrations or ventilation quantities may be required. Outside assistance may be needed if repeated efforts fail to produce a successful hypothesis or if the information required calls for instruments and procedures that are not available in-house.

Results of the Investigation

Analysis of the information collected during your IAQ investigation could produce any of the following results:

The apparent cause(s) of the complaint(s) are identified.

Remedial action and follow-up evaluation will confirm whether the hypothesis is correct.

Other IAQ problems are identified that are not related to the original complaints.

These problems (e.g., HVAC malfunctions, strong pollutant sources) should be corrected when appropriate.

A better understanding of potential IAQ problems is needed in order to develop a plan for corrective action.

It may be necessary to collect more detailed information and/or to expand the scope of the investigation to include building areas that were previously overlooked. Outside assistance may be needed.

The cause of the original complaint cannot be identified.

A thorough investigation has found no deficiencies in HVAC design or operation or in the control of pollutant sources, and there have been no further complaints. In the absence of new complaints, the original complaint may have been due to a single, unrepeated event or to causes not directly related to IAQ.

Using Outside Assistance

Some indoor air quality problems may be difficult or impossible for in-house investigators to resolve. Special skills or instruments may be needed. Other factors can also be important, such as the benefit of having an impartial outside opinion or the need to reduce potential liability from a serious IAQ problem. You are best able to make the judgment of when to bring in an outside consultant. See *Section 8* for a discussion of hiring professional assistance to solve an IAQ problem.

INITIAL WALKTHROUGH

An investigation may require one or many visits to the complaint area. The amount of preparatory work needed before the initial walkthrough varies with the nature and scope of the complaint and the expertise of the investigator, among other factors. For example, an in-house investigator who is already familiar with the layout and mechanical system in the building may begin responding to a complaint about discomfort by going directly to the complaint area to check the thermostat setting and see whether air is flowing from the supply outlets.

If the investigator is not familiar with the building or is responding to complaints that suggest a serious health problem, more preparation may be needed before the initial walkthrough. The activities listed below can be directed at a localized "problem area" or extended to include the entire building:

Collect easily-available information about the history of the building and of the complaints.

Identify known HVAC zones and complaint areas.

Begin to identify potential sources and pollutants (e.g., special use areas near the complaint location). Having a copy of mechanical and floor plans can be helpful at this stage, especially if they are reasonably up-to-date.

Notify the building occupants of the upcoming investigation.

Tell them what it means and what to expect.

Identify key individuals needed for access and information.

A person familiar with the HVAC systems in the building should be available to assist the investigator at any time during the onsite phase. Individuals who have complained or who are in charge of potential sources (e.g., housekeeping, non-HVAC equipment) should be aware that their information is important and should be contacted for appointments or telephone interviews if they will not be available during the onsite visit.

The initial walkthrough provides an opportunity to question complainants about the nature and timing of their symptoms and to briefly examine the immediate area of the complaint. The investigator attempts to identify pollutant sources and types and observes the condition and layout of the HVAC system serving the complaint area. Facility staff can be asked to describe the operating schedule of equipment. Obvious problems (e.g., blocked diffusers, malfunctioning air handlers) can be corrected to see if the complaints disappear. The walkthrough can solve many routine IAQ problems and will suggest directions for a more complex investigation, should one be necessary.

Some investigators avoid taking any measurements during the initial walk-through so that they are not distracted from "getting the big picture." Others find that using smoke sticks, digital thermometers, and direct reading CO_2 meters or detector tubes to take occasional measurements helps them develop a feel for the building.

It may help to keep the following questions in mind during the initial walkthrough:

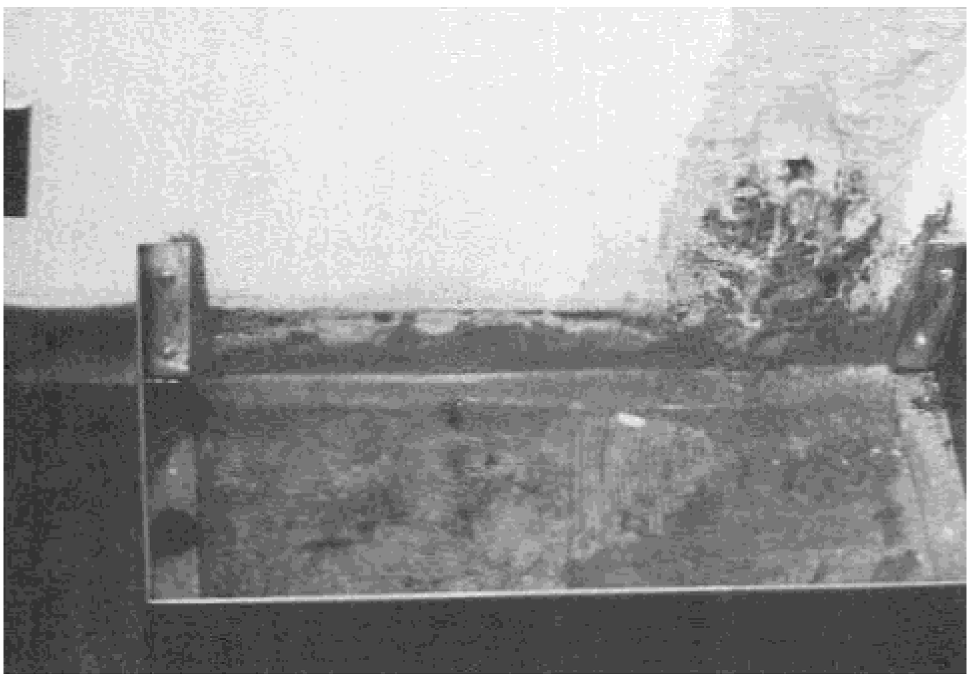
Are there obvious pollutant sources? Do they appear to be adequately controlled?

- Are pollutant indicators present, such as odors, excessive dust, or staining?
- Are there sanitation problems (e.g., debris near outdoor air intake, visible mold growth, major water damage) that could be introducing air contaminants?
- Are there any conditions or activities occurring in or near the building that could be related in timing, location and health effects to the complaints?

Are there any deficiencies in the HVAC system that serves the complaint area?

- Does equipment serving the area (e.g., thermostats, diffusers, fans, dampers, filters) appear to be operating, clean, and in good condition?
- Do operating procedures exist, and does the staff follow them?
- Do records indicate that the system was commissioned (set, tested, and balanced) after construction?
- Do records indicate that system components are regularly inspected, calibrated, and adjusted?

This improvised catch basin is intended to collect water seeping into the building from below grade. Although the catch basin "solves" the problem of uncontrolled water leakage, it also provides an indoor location that could support the growth of microbiologicals and create IAQ problems.



Are there pathways and pressure differences which could be moving contaminants into the complaint area from the outdoors or from other parts of the building?

COLLECTING ADDITIONAL INFORMATION

Additional information will be needed if the initial walkthrough does not identify the cause of the problem. The following pages present techniques for collecting information about the occupant complaints, HVAC system, pollutant pathways, and pollutant sources and using that information to develop a hypothesis that could explain the problem. Common sense will suggest the appropriate sequence of steps during this part of the investigation. For example, if the complaint is limited to a single room, it makes sense to evaluate pollutant pathways into that room before attempting to inventory sources in locations outside of, but connected to, the complaint area. On the other hand, if the complaint involves a recognizable odor (e.g., exhaust fumes), it may be more practical to begin by locating the potential source(s) of the odor before trying to identify pollutant pathways.

Forms and checklists such as the samples provided in this document (modified if needed) can help investigators to record information in an organized way. Small copies of basic floor plans, such as fire evacuation plans, are convenient for noting locations of observations.

Any instruments that will be used should be inspected to make sure they are in working order and calibrated. IAQ investigations generally include the use of, at a minimum: heatless chemical smoke devices and instruments for measuring temperature and humidity.

Carbon dioxide measuring devices (detector tubes with a hand pump or a direct reading meter) are helpful for most investigations. Other instruments may be needed as the investigation progresses. See *Appendix A* for additional guidance on common IAQ measurements.

Tools for Collecting Information

The following pages present strategies, tools, and forms for the investigator to use during an in-depth investigation. The **Incident Log** shown below (and in Tab V) can be used to track the course of an investigation from the receipt of the original complaint.

SEE COMPLETE FORM PAGE 183

Sample Form

Incident Log

			Investigation Record (check the forms that were used)										
File Number	Date	Problem Location	Complaint Form	Occupant Interview	Occupant Diary	Log of Activities	Zone/Room Record	HVAC Checklist	Pollutant Pathway	Source Inventory	Hypothesis Form	Outcome / Comments	Log Entry By (initials)

COLLECTING OCCUPANT INFORMATION

Strategies	Tools
Review existing information about complaints	▪ Existing Records ▪ IAQ Complaint Form ▪ Incident Log
Collect additional information from occupants	▪ Occupant Interview ▪ Occupant Diary

An initial walkthrough may uncover problems such as this unsanitary condition in the HVAC system. Bird droppings have collected in an air supply plenum near an outdoor air intake that was not protected by a birdscreen.

The discussion that follows has been divided into categories of occupant data, HVAC system data, pollutant pathway data, and source data. However, the suggestions for collecting and using information reflect the interdependence of these factors. For example, the operation of the air distribution system affects pollutant pathways, and the air distribution system can also be a source of pollutants.

Indoor air quality-related complaints may develop from a variety of causes. Neither the discussion of strategies for collecting information nor the suggestions for interpreting data can present the full range of possible situations encountered in buildings. They are intended to present a problem-solving approach that can help facility staff to understand and resolve many common indoor air quality problems. If you decide to hire outside professionals to resolve your IAQ complaint, this discussion of strategies and tools should help you to understand and oversee their investigative work.

COLLECTING INFORMATION ABOUT OCCUPANT COMPLAINTS

Occupant data falls into two categories: complaints of discomfort or other symptoms (e.g., teary eyes, chills) and perceptions of building conditions (e.g., odors, draftiness). Investigators can gather valuable information about potential indoor air problems from listening to occupants, and use that information for:

- defining the complaint area within the building
- suggesting directions for further investigation, either by identifying other events that seem to happen at the same time as the incidents of symptoms or discomfort, or by identifying possible causes for the types of symptoms or discomfort that are occurring
- indicating potential measures to reduce or eliminate the problem

Review Existing Records of Complaints

If there is a record of occupant complaints, a review of that record can help to define the location of the IAQ problem and identify people who should be interviewed as part of the investigation. Information about the history of complaints could also stimulate theories about potential causes of the problem.

Interview Occupants

The most obvious way to collect information from building occupants is to talk to them in person. If it is not possible to interview everyone who has complained about building conditions, the investigator should attempt to interview a group of individuals that reflect the concerns of the affected areas.

The investigation may also include occupant interviews with building occupants who do not have complaints. Then conditions in the complaint area can be compared to conditions in similar building locations where there are no complaints.

A sample **Occupant Interview** form is shown here (there is another copy in Tab V). It can also be presented in a written form in order to get information from more people than can be interviewed. The following key points will help interviews to be productive:

- Read the discussion of evaluating occupant data before you conduct interviews, to be certain that you understand what sort of information is needed.
- Make a copy of the interview form for each person you speak with, and use the form to record the answers to your questions.
- Choose a location in which the person you are interviewing feels comfortable to speak freely.
- Explain that the interview is intended to help discover and correct the cause of the complaints. Encourage the person you are interviewing to join in this cooperative problem-solving effort.
- Give the person you are interviewing enough time to think about your questions.
- If complainants are reluctant to answer questions about health symptoms, respect their desire for privacy. Planning for how to maintain this privacy is warranted, and in some cases may be mandated.
- Feel free to expand the interview by adding questions that help to improve your understanding or explore their hypotheses (or your own) about what may be causing the problem. Always be open to answers that may not fit your hypotheses.
- You may sometimes need to clarify a question by giving examples of the sort of information you are interested in. Try to provide more than one example so that you don't seem to be telling the person the answer you want. Be particularly cautious about mentioning specific health effects.

Sample Form

Occupant Interview

SYMPTOM PATTERNS

What kind of symptoms or discomfort are you experiencing?

Are you aware of other people with similar symptoms or concerns?
Yes____ No____

If so, what are their names and locations?

Do you have any health conditions that may make you particularly susceptible to environmental problems?

TIMING PATTERNS

When did your symptoms start?

SEE COMPLETE FORM PAGE 185

The **Occupant Interview** includes many basic points that are found in questionnaires used by professional IAQ investigators. It is important to note, however, that this form is not called a "questionnaire." Formal questionnaires may be useful for quantitative epidemiology, IAQ research, complex IAQ investigations, or when litigation is a possibility. In these cases, questionnaires must be carefully designed and executed by people with an understanding of representative sampling and expertise in public health, industrial hygiene, or medicine. Use of questionnaires for such purposes is beyond the scope or expertise of most in-house investigations; if such questionnaire data is needed, building owners and managers should use professionals.

Ask Occupants and Facility Staff to Keep More Detailed Records

Many events occur simultaneously in and around a complex building, and it can be very difficult to judge which of those events might be related to the IAQ complaints. In trying to resolve stubborn problems, professional investigators sometimes ask occupants and facility staff to keep day-by-day records. Occupants are asked to record the date and time of symptoms, where they are when the symptoms appear, and any other information that might be useful. Such information could include observations about the severity and duration of symptoms and comments on weather conditions, events, and activities that are happening at the same time. Facility staff are asked to record the date and time of events such as maintenance work, equipment cycles, or deliveries. If symptoms seem to occur at particular times of day, staff can focus their attentions on recording events that occur before and during those periods. Such records are likely to produce more accurate and detailed information than can be obtained by relying on memory. (Use the **Occupant Diary** and the **Log of Activities and System Operations** shown here and included in Tab V.)

Sample Form
Occupant Diary

On the form below, please record each occasion when you experience a symptom of ill-health or discomfort that you think may be related to an environmental condition in the building.

Time/Date	Location	Symptom	Severity/Duration	Comments

Sample Form
Log of Activities and System Operations

On the form below, please record your observations of HVAC system operation, maintenance activities, and any other information that you think may be helpful in identifying the cause of IAQ complaints in this building. Please report any other observations (e.g., weather, other associated events) that you think may be important as well.

Equipment and activities of particular interest:
Air Handler(s): ____________________
Exhaust Fan(s): ____________________
Other Equipment or Activities: ____________________

Date/Time	Day of Week	Equipment Item/Activity	Comments

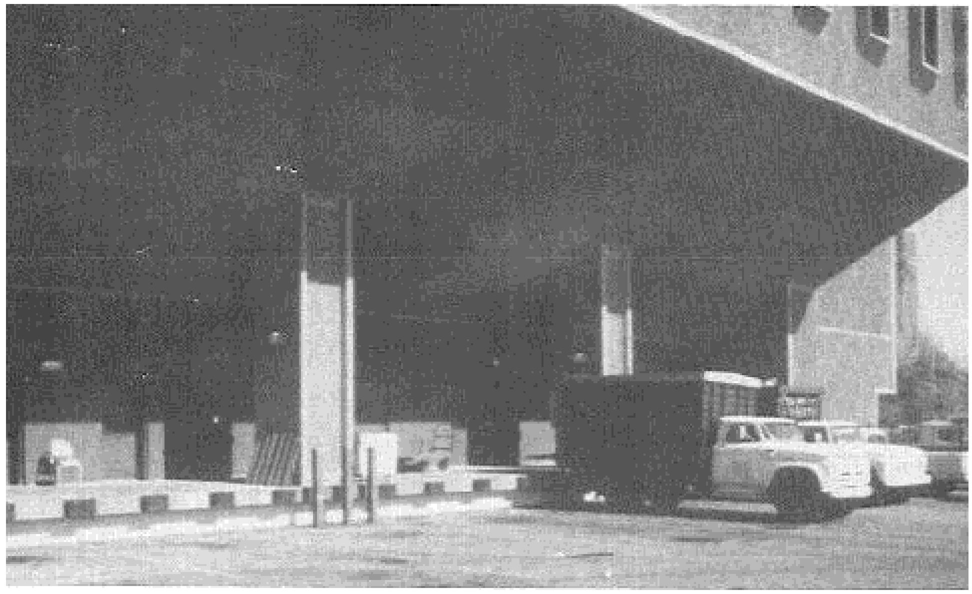
SEE COMPLETE FORMS PAGES 187 AND 189

USING THE OCCUPANT DATA

The pattern of complaints within the building helps to define the complaint area. The timing of symptoms and the types of symptoms reported may provide clues about the cause of the problem.

Strategies for Using Occupant Data

- Define the complaint area
- Look for timing patterns
- Look for symptom patterns



Exhaust fumes are drawn into this building's outdoor air intake when trucks are idling at the nearby loading dock. Tools such as the Occupant Diary and Log of Activities and System Operation can help to identify intermittent pollutant sources such as this one.

SPATIAL PATTERNS	SUGGESTIONS
Widespread, no apparent spatial pattern	n Check ventilation and temperature control for entire building. n Check outdoor air quality. n Review sources that are spread throughout building (e.g., cleaning materials). n Consider explanation other than air contaminants.
Localized (e.g., affecting individual rooms, zones, or air handling systems)	n Check ventilation and temperature control within the complaint area. n Review pollutant sources affecting the complaint area. n Check local HVAC system components that may be acting as sources or distributors of pollutants.
Individual(s)	n Check for drafts, radiant heat (gain or loss), and other localized temperature control or ventilation problems near the affected individual(s). n Review local pollutant source(s) near the affected individual(s). n Consider that common background sources may affect only susceptible individuals. n Consider the possibility that individual complaints may have different causes that are not necessarily related to the building (particularly if symptoms differ among the individuals).

Define the Complaint Area

Use the spatial pattern (locations) of complaints to define the complaint area. Building locations where symptoms or discomfort occur define the rooms or zones that should be given particular attention during the initial investigation. However, the complaint area may need to be revised as the investigation progresses. Pollutant pathways can cause occupant complaints in parts of the building that are far removed from the source of the problems.

Look for Timing Patterns

Look for patterns in the timing of complaints. The timing of symptoms and complaints can indicate potential causes for the complaints and provide directions for further investigation. Review the data for cyclic patterns of symptoms (e.g., worst during periods of minimum ventilation or when specific sources are most active) that may be related to HVAC system operation or to other activities in and around the building.

TIMING PATTERNS	SUGGESTIONS
Symptoms begin and/or are worst at the start of the occupied period	■ Review HVAC operating cycles. Emissions from building materials, or from the HVAC system itself, may build up during unoccupied periods.
Symptoms worsen over course of occupied period	■ Consider that ventilation may not be adequate to handle routine activities or equipment operation within the building.
Intermittent symptoms	■ Look for daily, weekly, or seasonal cycles or weather-related patterns, and check linkage to other events in and around the building.
Single event of symptoms	■ Consider spills, other unrepeated events as sources.
Recent onset of symptoms	■ Ask staff and occupants to describe recent changes or events (e.g., remodeling, renovation, redecorating, HVAC system adjustments, leaks, or spills).
Symptoms relieved on leaving the building, either immediately, overnight, or (in some cases) after extended periods away from the building	■ Consider that the problem is likely to be building-related, though not necessarily due to air quality. Other stressors (e.g., lighting, noise) may be involved.
Symptoms never relieved, even after extended absence from building (e.g., vacations)	■ Consider that the problem may not be building-related.

The following chart lists some common symptom groups that can be related to indoor air quality, along with possible sources or causes of those symptoms. Building managers are cautioned that this is only a partial listing.

Look for Symptom Patterns

Look for patterns in the types of symptoms or discomfort. IAQ investigations often fail to prove that any particular pollutant or group of pollutants are the cause of the problem. Such causal relationships are extremely difficult to establish. There is little information available about the health effects of many chemicals. Typical indoor levels are much lower than the levels at which toxicology has found specific effects. Therefore, it may be more useful to look for patterns of symptoms than for specific pollutant and health effect relationships.

Investigators who are not medically trained cannot make a diagnosis and should not attempt to interpret medical records. Also, confidentiality of medical information is protected by law in some jurisdictions and is a prudent practice everywhere.

SYMPTOM PATTERNS	SUGGESTIONS
THERMAL DISCOMFORT	■ Check HVAC condition and operation. ■ Measure indoor and outdoor temperature and humidity (see Figure 6-2 on page 57). See if extreme conditions exceed design capacity of HVAC equipment. ■ Check for drafts and stagnant areas. ■ Check for excessive radiant heat gain or loss.
COMMON SYMPTOM GROUPS Headache, lethargy, nausea, drowsiness, dizziness	If onset was acute, arrange for medical evaluation, as the problem may be carbon monoxide poisoning. ■ Check combustion sources for uncontrolled emissions or spillage. Check outdoor air intakes for nearby sources of combustion fumes. ■ Consider evacuation/medical evaluation if problem isn't corrected quickly. ■ Consider other pollutant sources. ■ Check overall ventilation; see if areas of poor ventilation coincide with complaints.
Congestion; swelling, itching or irritation of eyes, nose, or throat; dry throat; may be accompanied by non-specific symptoms (e.g. headache, fatigue, nausea)	May be allergic, if only small number affected; more likely to be irritational response if large number are affected. ■ Urge medical attention for allergies. ■ Check for dust or gross microbial contamination due to sanitation problems, water damage, contaminated ventilation system. ■ Check outdoor allergen levels (e.g., pollen counts). ■ Check closely for sources of irritating chemicals such as formaldehyde or those found in some solvents.
Cough; shortness of breath; fever, chills and/or fatigue after return to the building	May be hypersensitivity pneumonitis or humidifier fever. A medical evaluation can help identify possible causes. ■ Check for gross microbial contamination due to sanitation problems, water damage, or contaminated HVAC system.
Diagnosed infection	May be Legionnaire's disease or histoplasmosis, related to bacteria or fungi found in the environment. ■ Contact your local or State Health Department for guidance.
Suspected cluster of rare or serious health problems such as cancer, miscarriages	■ Contact your local or State Health Department for guidance.
OTHER STRESSORS Discomfort and/or health complaints that cannot be readily ascribed to air contaminants or thermal conditions	■ Check for problems with environmental, ergonomic, and job-related psychosocial stressors.

Figure 6-2 shows the range of temperatures and relative humidities that fall within the comfort zone for most individuals dressed in "typical" clothing and involved in light, mostly sedentary activity. Recent research suggests that indoor air quality is judged to be worse as temperatures rise above 76°F, regardless of the actual air quality.

There is considerable debate among researchers, IAQ professionals, and health professionals concerning recommended levels of relative humidity. In general, the range of humidity levels recommended by different organizations seems to be 30% to 60%. Relative humidities below this level may produce discomfort from dryness. On the other hand, maintaining relative humidities at the lowest possible level helps to restrict the growth of mold and mildew. The concerns (comfort for the most part) associated with dry air must be balanced against the risks (enhanced microbiological growth) associated with humidification. If temperatures are maintained at the lower end of the comfort range (68 - 70°F) during heating periods, relative humidity in most climates will not fall much below 30% (also within the comfort range) in occupied buildings.

FIGURE 6-2: Acceptable Ranges of Temperature and Relative Humidity During Summer and Winter [1]

Relative Humidity	Winter Temperature	Summer Temperature
30%	68.5°F - 76.0°F	74.0°F - 80.0°F
40%	68.5°F - 75.5°F	73.5°F - 79.5°F
50%[2]	68.5°F - 74.5°F	73.0°F - 79.0°F
60%	68.0°F - 74.0°F	72.5°F - 78.0°F

[1] Applies for persons clothed in typical summer and winter clothing, at light, mainly sedentary activity.

[2] See left for discussion of relative humidities.

SOURCE: Adapted from ASHRAE Standard 55-1981, Thermal Environmental Conditions for Human Occupancy

COLLECTING INFORMATION ABOUT THE HVAC SYSTEM

IAQ complaints often arise because the quantity or distribution of outdoor air is inadequate to serve the ventilation needs of building occupants. Problems may also be traced to air distribution systems that are introducing outdoor contaminants or transporting pollutants within the building.

The investigation should begin with the components of the HVAC system(s) that serve the complaint area and surrounding rooms, but may need to expand if connections to other areas are discovered. Your goal is to understand the design and operation of the HVAC system well enough to answer the following questions:

- Are the components that serve the immediate complaint area functioning properly?
- Is the HVAC system adequate for the current use of the building?
- Are there ventilation (or thermal comfort) deficiencies?
- Should the definition of the complaint area be expanded based upon the HVAC layout and operating characteristics?

An evaluation of the HVAC system may include limited measurements of temperature, humidity, air flow, and CO_2, as well as smoke tube observations. Complex investigations may require more extensive or sophisticated measurements of the same variables (e.g., repeated CO_2 measurements taken at the same location under different operating conditions, continuous temperature and relative humidity measurements recorded with a data logger). A detailed engineering study may be needed if the investigation discovers problems such as the following:

- airflows are low
- HVAC controls are not working or are working according to inappropriate strategies
- building operators do not understand (or are unfamiliar with) the HVAC system

WHAT DO YOU KNOW SO FAR?

- Use the Hypothesis Form on page 223 to make brief notes after reviewing the occupant data.
- Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.
- Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed (See *Section 8* for guidance on hiring outside assistance.)

COLLECTING HVAC SYSTEM INFORMATION

Strategies	Tools
Review existing documentation on HVAC design, installation, and operation	Collect: ■ design documents, testing and balancing reports ■ operating instructions, control manufacturer's installation data
Talk to facilities staff	Ask facilities staff to record their observations of equipment cycles, weather conditions, and other events using *Log of Activities and System Operations*
Inspect system layout, condition, and operation	Use: ■ Zone/Room Record ■ HVAC Checklist - Short Form and/or ■ HVAC Checklist - Long Form ■ thermometer and sling psychrometer (or electronic equivalent) to measure temperature and humidity ■ micromanometer (or equivalent) to measure pressure differentials • 0-2" and 0-10" water gauge (w.g.) to measure at fans and intakes • 0-.25" w.g. with pitot tube to check airflow in ducts ■ chemical smoke for observing airflow patterns ■ a device to assess airflow from diffusers • rough quantitative: anemometer; velometer • accurate quantitative: flow hood ■ carbon dioxide measurement devices • detector tubes with a hand pump • direct reading meter
Use additional instruments as appropriate	Instruments often used by professional IAQ consultants include: ■ a hygrothermograph to log temperature and humidity ■ tracer gas and measurement equipment ■ a device to measure airborne particulates ■ measurement devices for carbon monoxide and other contaminants of interest

Review Documentation on HVAC Design, Installation, and Operation

A review of existing documentation (e.g., plans, specifications, testing and balancing reports) should provide information about the original design and later modifications, particularly:

- the type of HVAC system (e.g., constant volume, VAV)
- locations and capacities of HVAC equipment serving the complaint area
- the planned use of each building area
- supply, return, and exhaust air quantities
- location of the outdoor air intake and of the supply, return, and exhaust registers, diffusers, and grilles that serve the complaint area

The most useful way to record this information is to make a floor plan of the complaint area and surrounding rooms. You may be able to copy an existing floor plan from architectural or mechanical drawings, fire evacuation plans, or some other source.

If there is no documentation on the mechanical system design, much more on-site inspection will be required to understand the HVAC system. The HVAC system may have been installed or modified without being commissioned, so that it may never have performed according to design. In such cases, good observations of airflow and pressure differentials are essential. In addition, load analyses may be required.

Talk to Facility Staff

Facility staff can provide important current information about equipment operating and maintenance schedules and breakdowns or other incidents. There may be inspection reports or other written records available for review. Staff members who are familiar with building systems in general and with the specific features of the building under investigation can be very helpful in identifying conditions that may explain the indoor air quality complaints. Some facility operators have extensive preventive maintenance programs. On the other hand, discussion could reveal that facility staff are not operating the building according to its design, because:

- they do not understand the design logic of the HVAC system
- they have been asked to run the HVAC system at the lowest possible energy cost
- they do not have the manpower to operate the building properly
- the HVAC system has not been modified to accommodate changes in the use of space or increases in the occupant population

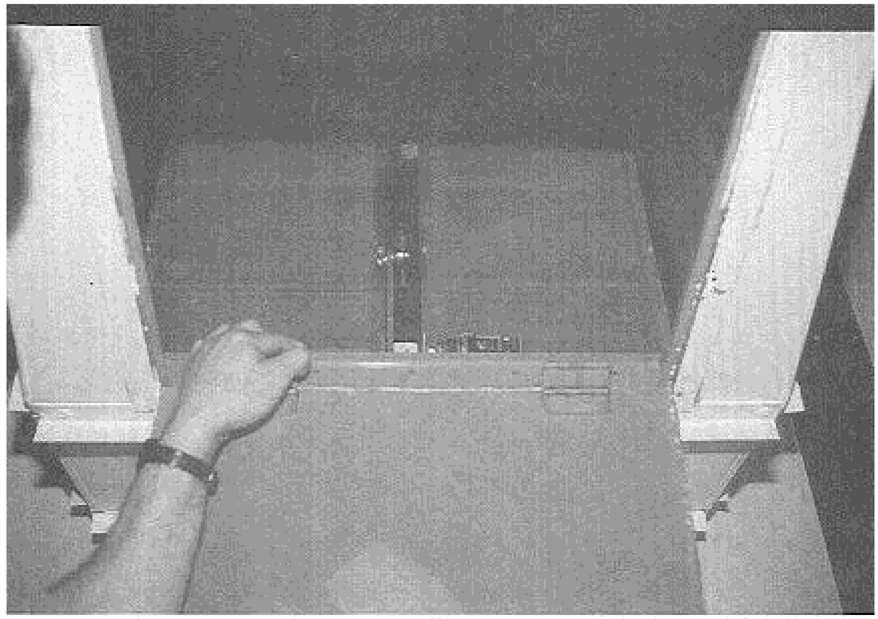
Staff may have noticed occupant activities that are indicators of inadequate ventilation or poorly-controlled temperatures, such as:

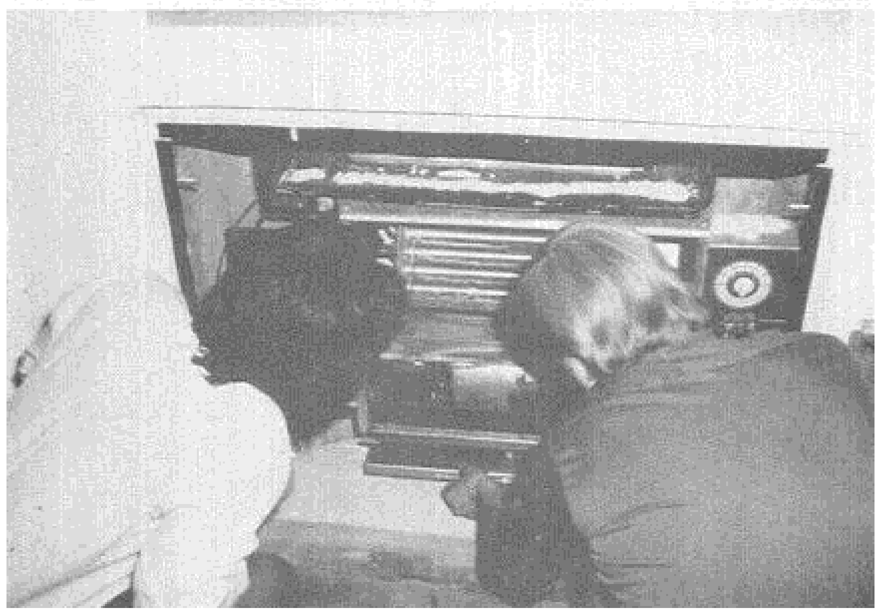
- desktop fans, heaters, or humidifiers
- supply diffusers blocked off with tape or cardboard
- popped-up ceiling tiles
- interference with thermostat settings

IAQ complaints are often intermittent. Discussions with staff may reveal patterns that relate the timing of complaints to the cycles of equipment operation or to other events in the building such as painting, installation of new carpeting, or pest control. These patterns are not necessarily obvious. Keeping a day-to-day record may help to clarify subtle relationships between occupant symptoms, equipment operation, and activities in and around the building. (See **Occupant Diary** and **Log of Activities and System Operations** on page 52 and in Tab V.) Staff members may have theories about the cause of the problem.

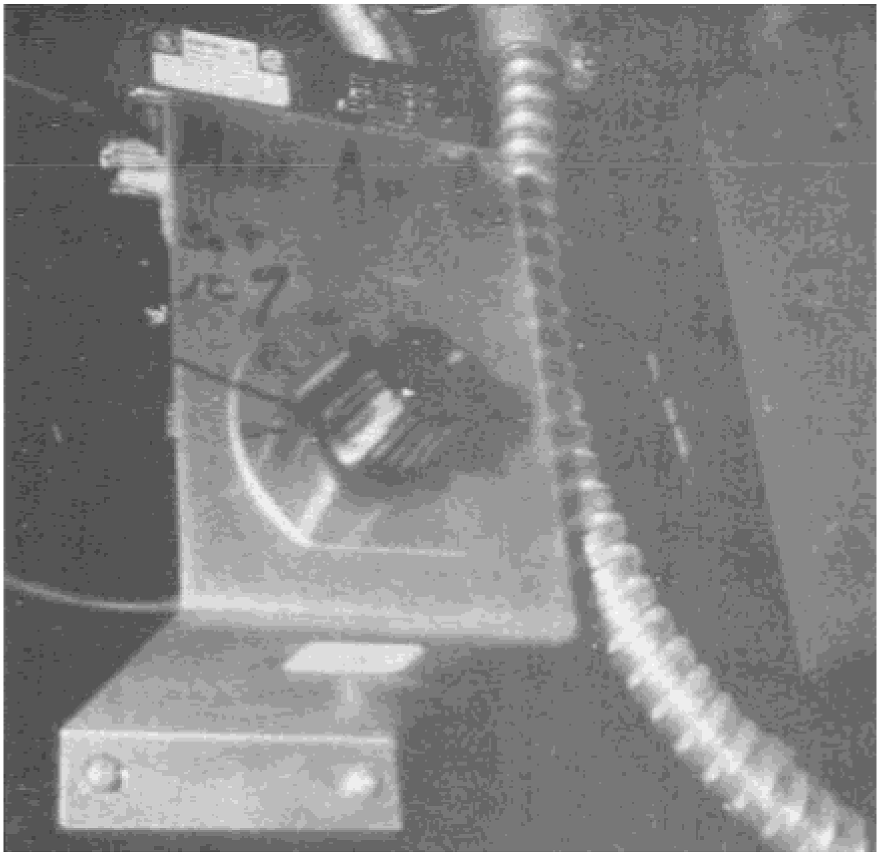
Inspect System Layout, Condition, and Operation

If the building is new or if there is a preventive maintenance program with recent





Above: An investigation of this building revealed no problems with the HVAC system, although the amount of outdoor air was very low. In a more thorough inspection of the HVAC system, investigators found that the wiring to this outdoor air damper motor had never been connected. No outdoor air was entering the building through the intake controlled by this damper. Below: These investigators are examining a perimeter fan-coil unit. Self-contained heating or cooling units such as this one are often overlooked during routine maintenance. There may be many such units in a single building, sometimes in remote or inaccessible locations.



The design specifications for this building called for a minimum 20% setting on the outdoor air damper control. Facility staff lowered the minimum outdoor air setting to 10% in order to save energy and reduce operating costs. As a result, the building was underventilated whenever outdoor temperatures were either very hot or very cold.

test and balance reports, it is possible (but not necessarily likely) that the HVAC system is functioning according to its original design. Otherwise it is probable that one or more features of building usage or system operation have changed in ways that could affect indoor air quality.

Elements of the on-site investigation can include (but are not limited to) the following:

Check temperature and/or humidity to see whether the complaint area is in the comfort range.

Take more than one measurement to account for variability over time and from place to place. Compare to Figure 6-2 on page 57 (see also *Appendix B*).

- Check thermostat operation.
- Check whether the supply air temperature corresponds to the design criteria.
- Use a hygrothermograph (if available) to log temperature and humidity changes in the complaint area.

Check for indicators of inadequate ventilation.

- Check supply diffusers to see if air is moving (using chemical smoke). If it is not, confirm that the fan system is operating, and then look for closed dampers, clogged filters, or signs of leaks.
- Compare design air quantities (if available) to building codes for the current occupancy or ventilation guidelines (e.g., ASHRAE 62-1989, see *Appendix B*). If the HVAC system, performing as designed, would not provide enough ventilation air for current needs, then there is good reason to believe that actual ventilation rates are inadequate.
- Measure carbon dioxide (CO_2) in the complaint area to see whether it indicates ventilation problems. (See *Appendix A* for a discussion of techniques for measuring and interpreting CO_2 concentrations.)
- Measure air quantities supplied to and exhausted from the complaint area, including calculation of outdoor air quantities (see *Appendix A* for further guidance). Be aware of damper settings and equipment cycles when you are measuring (e.g., are you evaluating minimum outdoor air, "normal" conditions, or maximum airflow?). Note that evaluation of variable air volume (VAV) systems requires considerable expertise. Compare the measured air quantities to your mechanical system design specifications and applicable building codes. Also compare ventilation rates to ASHRAE 62-1989. Some of the ventilation recommendations of ASHRAE 62-1989 are reproduced in *Appendix B.*

Check that equipment serving the complaint area (e.g., grilles, diffusers, fans) is operating properly.

- Confirm the accuracy of reported operating schedules and controls sequences; for example, power outages may have disrupted time clocks, fans reported as "always running" may have been accidentally switched off, and controls can be in need of calibration.

- Check to see that equipment is properly installed. For example, look for shipping screws that were never removed or fans that were reversed during installation, so that they move air in the wrong direction.

Compare the current system to the original design.

- Check to see that all equipment called for in the original design was actually installed.
- See whether original equipment may have been replaced by a different model (i.e., a model with less capacity or different operating characteristics).

See whether the layout of air supplies, returns, and exhausts promotes efficient air distribution to all occupants and isolates or dilutes contaminants.

(See *Appendix A* for guidance on using chemical smoke to study airflow and mixing patterns and CO_2 to help determine the adequacy of ventilation.)

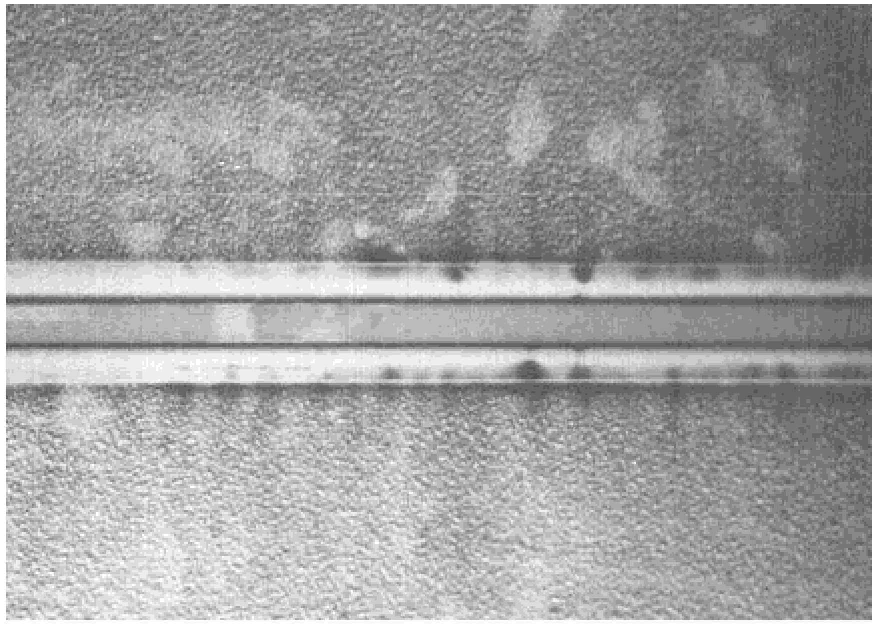
- If supplies and returns are close together, heatless chemical smoke can be used to check for short-circuiting (supply air that does not mix properly with air in the breathing zone, but moves directly to the return grille). CO_2 can also be used to evaluate air mixing.
- Use heatless chemical smoke to observe airflow patterns within the complaint area and between the complaint area and surrounding spaces, including outdoors. Compare airflow directions under various operating conditions.
- If the system layout includes ceiling plenums, look above the ceiling for interruptions such as walls or full-height partitions.

Consider whether the HVAC system itself may be a source of contaminants.

- Check for deterioration or unsanitary conditions (e.g., corrosion, water damage or standing water, mold growth or excessive dust in ductwork, debris or damaged building materials in ceiling plenums).
- If the mechanical room serves as a mixing plenum (i.e., return and outdoor air are drawn through the room into the air handler), check very carefully for potential contaminants such as stored solvents and deteriorated insulation.

Use the forms provided in this document to inspect the HVAC system.

- Use the **Zone/Room Record** to describe the ventilation system serving the complaint area and surrounding rooms or zones. The **Zone/Room Record** is reproduced on page 62 and in Tab V.
- Use the HVAC Checklist (short and/or long form) to evaluate the condition of HVAC system components that affect air distribution and IAQ in the complaint area. A portion of the **HVAC Checklist-Short Form** is reproduced on page 62. **The HVAC Checklist - Long Form** is useful for more detailed examination of the system. Complete copies of both forms can be found in Tab V.



The dark streaks at the outlet of this supply diffuser could indicate a filtration problem. Poorly maintained or improperly sized filters can allow dirt to be distrib-uted through the building.

Sample Form

Zone/Room Record

This form is to be used differently depending on whether the goal is to prevent or diagnose IAQ problems. During development of a profile, this form should be used to record more general information about the entire building; during an investigation, the form should be used to record more detailed information about the complaint area and areas surrounding the complaint area or connected to it by pathways.

PROFILE AND DIAGNOSIS INFORMATION					DIAGNOSIS INFORMATION ONLY		
Building Area (Zone/Room)	Use**	Source of Outdoor Air*	Mechanical Exhaust? (Write "No" or estimate cfm airflow)	Comments	Peak Number of Occupants or Sq. Ft. Floor Area*	Total Air Supplied (in cfm)**	Outdoor Air Supplied per Person or per 150 sq. Ft. Area****

Sample Form

HVAC Checklist — Short Form

Sections 2, 4 and 6 and Appendix B discuss the relationships between the HVAC system and indoor air quality.

MECHANICAL ROOM

- Clean and dry? ________ Stored refuse or chemicals? ________
- Describe items in need of attention ________

MAJOR MECHANICAL EQUIPMENT

- Preventive maintenance (PM) plan in use? ________

Control System ________

Type ________

System operation ________

SEE COMPLETE FORMS PAGES 177 AND 191

USING THE HVAC SYSTEM DATA

As you review the HVAC data, consider whether the system is adequate to serve the use of the building and whether the timing, location, and impact of apparent deficiencies appear related to the IAQ complaint. Deficiencies in HVAC design, operation, or maintenance may exist without producing the complaint under investigation; some defects may not cause any apparent IAQ problems.

Strategies for Using the HVAC System Data

- Compare the original design to the current system.
- Compare the original uses of space to current uses.
- Consider the condition of the HVAC system.

HEALTH AND SAFETY CONSIDERATIONS FOR IAQ INVESTIGATORS

Normal safety precautions observed during routine operation of the building must be followed closely during IAQ inspections. When the IAQ investigator is not familiar with the mechanical equipment in that particular facility, an operator or engineer should be present at all times in equipment areas. Potential safety hazards include:

- electrocution
- injury from contacting fans, belts, dampers or slamming doors
- burns from steam or hot water lines
- falls in ventilation shafts or from ladders or roofs

Investigators evaluating building IAQ generally do not encounter situations in which specific personal protection measures (e.g., protective garments and respirators) are required. However, safety shoes and eyeglasses are generally recommended for working around mechanical equipment. When severe contamination is present (e.g., microbiological, chemical, or asbestos), IAQ investigators may need additional protection in the vicinity of certain building areas or equipment. Such decisions are site specific and should be made in consultation with an experienced industrial hygienist. General considerations include the following:

Microbiological: Care must be taken when serious building related illness (e.g., Legionnaire's disease) is under investigation or when extensive microbiological growth has occurred. Investigators with allergy problems should be especially cautious. The array of potential contaminants makes it difficult to know what sort of personal protection will be effective. At a minimum, investigators should minimize their exposure to air in the interior of ducts or other HVAC equipment unless respiratory protection is used. If there is reason to suspect biological contamination (e.g., visible mold growth), expert advice should be obtained about the kind of respiratory protection to use and how to use it. Possible protective measures against severe microbiological contamination include disposable coveralls and properly fitted respirators.

Chemical: Where severe chemical contamination is suspected, specific precautions must be followed if OSHA action levels are approached. Such instances rarely occur in IAQ investigations. One possible exception might be a pesticide spill in a confined space. In this case, an appropriate respirator and disposable coveralls may be needed.

Asbestos: An IAQ investigation often includes inspection above accessible ceilings, inside shafts, and around mechanical equipment. Where material suspected of containing asbestos is not only present, but also has deposited loose debris, the investigator should take appropriate precautions. This might include disposable coveralls and a properly fitted respirator.

Note: The requirements for proper fit, physical condition of the wearer, and other considerations involved in selection of the proper respirator must be evaluated by an occupational safety and health specialist. There is a NIOSH Respirator Decision Logic for proper respirator selection, and OSHA has regulations for an appropriate respirator protection program.

When the IAQ investigator is not familiar with the mechanical equipment in that particular facility, an operator or engineer should be present at all times in equipment areas.

ALL SYSTEMS	SUGGESTIONS
Ventilation and temperature control zones	■ Revise definition of complaint area (if needed) to add spaces linked to the original complaint area by ductwork or controls. ■ Check to see that thermostats are properly located and function properly.
Changes in equipment	■ Note equipment changes that could be affecting the system's performance (e.g., removal or addition of equipment, replacement by a different model).
Operating cycles	■ Review operating procedures for occupied and unoccupied periods. ■ Compare timing of occupied/unoccupied periods to equipment cycles and occupant complaints. Confirm that time clocks are reading the actual time. See ASHRAE 62-1989 for suggested lead times to allow proper flushing before occupants arrive. In some cases (e.g., warm, humid climates), fans may need to operate during unoccupied periods to prevent mold growth or other problems.

Compare the Original Design to the Current HVAC System

Consider the original HVAC design and compare it to the current equipment, layout, and controls. A variety of HVAC system designs have been used in public and commercial buildings. The type of system used in your building affects the control of ventilation air quantities and distribution, as well as thermal comfort. See *Appendix B* for a discussion of HVAC system types.

Use HVAC Data to Evaluate Mitigation Measures

As you use the HVAC data to evaluate potential mitigation measures, review the suggestions made in both the box on the facing page for all HVAC systems and in the box on this page for the type of HVAC system in your building.

SYSTEM TYPES	SUGGESTIONS
No mechanical ventilation or exhaust only	n Identify the source(s) of ventilation air (e.g., operable windows, doors propped open). n Check whether the location of open windows, doors, or other openings promotes the introduction of odors or contaminants.
Room units (e.g., unit ventilators)	n Check whether outdoor air intakes are obstructed. Does their location promote the introduction of odors or contaminants? n Note design airflows in the complaint area (outdoor air, supply, return, and exhaust) and surrounding spaces; compare to ASHRAE 62-1989 and to actual measured airflows.
Constant volume	n Note design airflows in the complaint area (outdoor air, supply, return, and exhaust) and surrounding spaces; compare to applicable building codes, ASHRAE 62-1989, and to actual measured airflows. n Check whether outdoor air intakes are obstructed. Does their location promote the introduction of odors or contaminants? Check for unsanitary conditions. n Check outdoor air damper controls.
Variable air volume (VAV)	In addition to all suggestions made for constant volume systems: n Confirm whether the system design allows regulation of outdoor air quantities. Do VAV boxes have stops to ensure that minimum amounts of outdoor air are delivered at all times during occupied periods? Are the system controls providing a constant ventilation rate per person regardless of total system airflows? n Observe changes (if any) in airflow patterns within and around the complaint area as the VAV system throttles from maximum to minimum flow.

ROOM USE CHANGES	SUGGESTIONS
Increased occupant density	n Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines. n Compare minimum outdoor air quantities to the original design, applicable building codes, and ASHRAE 62-1989 guidelines.
Change in type of occu-pant population	For example introduction of a more physically active group of occupants can change thermal comfort requirements. n Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines. n Compare minimum outdoor air quantities to the original design, applicable building codes, and ASHRAE 62-1989 guidelines. n Check for low-level contaminant sources.
Additional non-HVAC equipment	n Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines. n Consider the need for local exhaust at point sources of contaminants.
Conversion to or addition of special uses	Example: Modifications that convert or add such special uses as smoking lounges, print shops, or kitchen facilities may also require changes in the operation of the HVAC system. n Check pressure relationships between special use areas and surrounding spaces. n Consider the need for local exhaust at point sources of contaminants.
Rearrangement of work stations (e.g., relocation of partitions)	n Check that thermostats are properly located. Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines. n Check layout of supplies, returns, and exhausts. n Check to make sure that partitions do not block proper air circulation.

Compare the Original Uses of Space to Current Uses

Compare the original uses of the complaint area and surrounding rooms to current uses of those areas. Indoor air quality problems often arise when the usage of rooms changes without corresponding adjustments to the HVAC system. For example, if ventilation appears to be a problem despite a properly-functioning HVAC system, the existing system may be inadequate to meet current needs.

Consider the Condition of the HVAC System

Consider whether the HVAC system is reasonably clean and functioning properly. Review the results of the onsite inspection. If you identified sanitary or operating problems in the HVAC system serving the complaint area, you may want to correct those problems and see whether the complaints are resolved before continuing with the investigation.

SYSTEM CONDITIONS	SUGGESTIONS
Unsanitary conditions ■ Moisture or standing water ■ Debris ■ Dust and/or mold growth	■ Correct sanitary problems and adopt necessary measures to prevent recurrence of problems.
HVAC malfunctions ■ Equipment breakdown ■ Obstructed diffusers or grilles ■ Air distribution or mixing problems: (e.g., equipment is out of balance, requires calibration, or needs other adjust-ment) ■ Air bypasses filters (due to loose filter tracks, incorrect filter size, or filter overloaded with dirt) ■ Air distribution system leaks (e.g., leaky ductwork; unin-tended openings in pressurized ceilings or in return air plenums)	■ Evaluate whether the HVAC defect could have caused the IAQ complaint. ■ Correct the malfunction(s), and see whether complaints are resolved. ■ Review maintenance program and revise as needed to prevent future problems.
HVAC functions properly. However, there is evidence of underventilation.	■ Consider what adjustments could be made to increase the supply of outdoor air (or decrease the ventilation demand) in the complaint area.

WHAT DO YOU KNOW SO FAR?

- Use the **Hypothesis Form** on page 223 to make brief notes.
- Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypoth-esis testing.)
- Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed (See *Section 8* for guidance on hiring outside assistance.)

COLLECTING INFORMATION ABOUT POLLUTANT PATHWAYS AND DRIVING FORCES

Unless the IAQ problem is caused by an obvious contaminant located in the complainant's immediate workspace, you will need to understand the patterns of airflow into and within the complaint area. Correction of IAQ problems often involves controlling pollutant movement through sealing of pollutant pathways or manipulation of the pressure relationships.

If the complaints being investigated are limited to a few areas of the building, pollutant pathways can be evaluated so that the complaint area is properly defined before conducting the source inventory. If complaints are spread throughout the building, evaluation of pathways could be a very time-consuming process, and it may be more practical to look for major contaminant sources before trying to discover how the contaminants move within the building.

Identify Pollutant Pathways

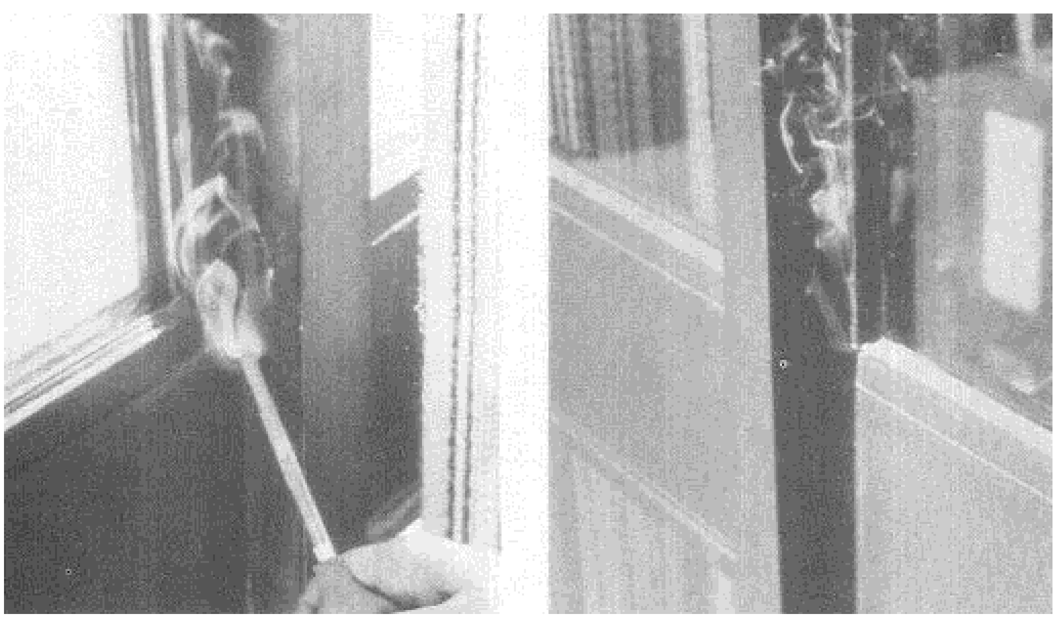
Architectural and mechanical pathways allow pollutants to enter the complaint area from surrounding spaces, including the outdoors. An examination of architectural and mechanical plans can help in developing a list of connections to surrounding areas. These include:

- doors
- operable windows
- stairways
- elevator shafts
- utility chases
- ductwork and plenums
- areas served by common HVAC controls (e.g., shared thermostats)

Onsite inspection is needed to confirm the existence of these connections and to identify other openings (e.g., accidental openings such as cracks and holes). Fire codes usually require that chases and hidden openings be firestopped. Check for the existence and condition of firestops in chases, especially those that connect both vertically and horizontally.

COLLECTING PATHWAY INFORMATION

Strategies	Tools
Identify pollutant pathways	n Architectural and mechanical drawings n Pollutant Pathway Form for Investigations n Sketch plan of complaint area
Observe direction of air movement	n Testing and balancing reports n Chemical smoke tests n Micromanometer or equivalent



Chemical smoke is being used to detect the direction and amount of airflow through this closed doorway. A building investigator must know how the ventilation in the building is designed to operate in order to decide whether the observed flow of smoke is appropriate.

The **Pollutant Pathway Form for Investigations** shown to the right can be used along with a sketch plan of the complaint area (similar to the example on page 70) to record pathways and directions of pollutant movement. A blank copy of the form is included in Tab V.

Sample Form

Pollutant Pathway for Investigations Form

Building Name ______________________ File Number __________

Address: ____

Completed By (name): ____________________________________

Rooms or Zones Connected to the Complaint Area by Pathways	Use	Pressure Relative to Complaint Area		Comments (e.g., potential pollutant sources)
		+/-	date/time	

SEE COMPLETE FORM PAGE 211

Observe Air Movement Direction

The airflow quantities shown in mechanical plans or in testing and balancing reports can be used to determine the direction of air movement intended by the designer. Onsite examination is necessary to determine the actual direction of airflow at each available pathway.

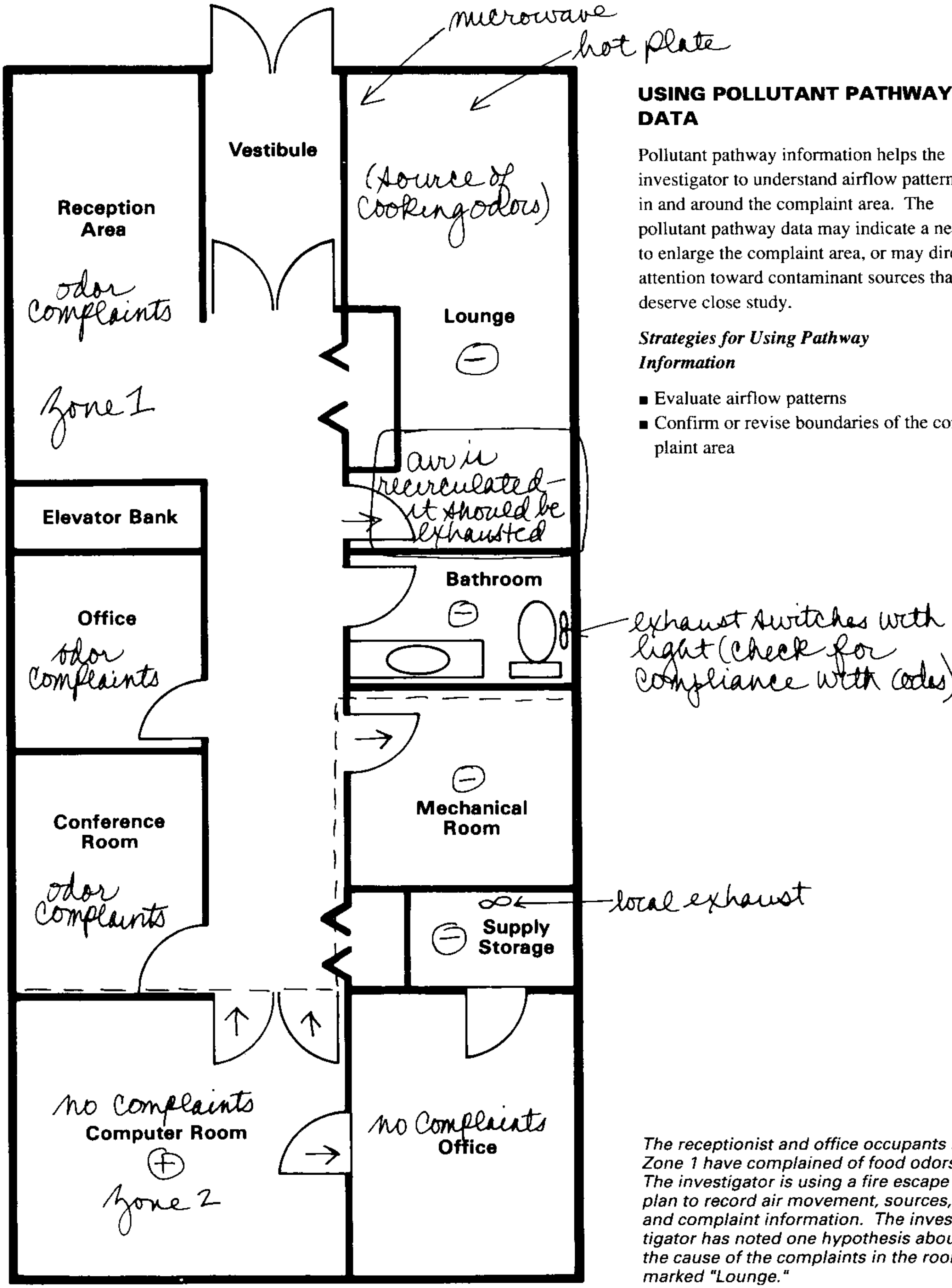
Chemical smoke tubes can be used to determine airflow directions between the complaint area and surrounding spaces (including the outdoors), and to reveal air circulation patterns within the complaint area. A micromanometer (or equivalent) can measure the magnitude of pressure differences between these areas. The sketch plan and the **Pollutant Pathway Form for Investigations** can be used to record the results.

It may be necessary to make observations under different conditions, as airflow direction can change depending upon weather conditions, windspeed and direction, equipment operation within the building, traffic through doors, and other factors (e.g., as VAV systems throttle back). Switching air handlers or exhaust fans on and off, opening and closing doors, and simulating the range of operating conditions in other ways can help to show the different ways that airborne contaminants move within the building. Dust tracking patterns around door frames can reveal the dominant direction of air and pollutant movement.

Some investigators study air movement by releasing a small amount of peppermint oil at the opening to a suspected pathway and asking an assistant to sniff for the "toothpaste" smell. If this technique is used, it is important that the assistant have an acute sense of smell. If the building is in use during the investigation, occupants may also notice the odor and could find it distracting. Some investigators prefer to use methods that release an odor during unoccupied periods. Investigators should note two common causes of false negative results (falsely concluding that no pathway exists):

- The nose quickly becomes tolerant of strong odors, so that the assistant may need to take a long rest (breathing fresh air) between tests.
- If there is substantial airflow through the pathway, the peppermint oil odor could be diluted so that it is imperceptible.

Tracer gases such as sulfur hexafluoride (SF_6) can provide qualitative and quantitative information on pollutant pathways and ventilation rates. Use of tracer gases to obtain quantitative results requires considerable technical expertise. If it appears that a sophisticated study of pathways (or ventilation rates) is required, you need to use trained investigators.



USING POLLUTANT PATHWAY DATA

Pollutant pathway information helps the investigator to understand airflow patterns in and around the complaint area. The pollutant pathway data may indicate a need to enlarge the complaint area, or may direct attention toward contaminant sources that deserve close study.

Strategies for Using Pathway Information

- Evaluate airflow patterns
- Confirm or revise boundaries of the complaint area

The receptionist and office occupants in Zone 1 have complained of food odors. The investigator is using a fire escape plan to record air movement, sources, and complaint information. The investigator has noted one hypothesis about the cause of the complaints in the room marked "Lounge."

Evaluate Airflow Patterns

Evaluate airflow patterns into and within the complaint area. Because of the complexity and variability of airflow patterns, investigators cannot be expected to understand how air moves within the building under all potential operating conditions. However, data on pathways and driving forces can help to locate potential pollutant sources and to understand how contaminants are transported to building occupants.

AIRFLOW PATTERNS	SUGGESTIONS
▪ Onsite observations	▪ Look for temporal patterns linking changes in airflow direction to incidents of complaints. ▪ Look for spatial patterns linking potential sources to the locations of complaints.

Confirm or Revise Boundaries of the Complaint Area

The discovery of unexpected pollutant pathways can show a need to study areas of the building that may be distant from the original complaint area.

COMPLAINT AREA	SUGGESTIONS
▪ Complaint area connected by architectural features to other areas ▪ Complaint area connected by mechanical system to other areas ▪ Unintentional pathways (e.g., cracks, holes)	▪ Check whether pressure relationships between complaint area and surrounding locations follows intent of ventilation design. ▪ Check whether air from other locations flows into the complaint area under some conditions. If so, consider expanding the investigation to inventory pollutant sources (and perhaps collect HVAC or occupant data) in those locations.

WHAT DO YOU KNOW SO FAR?

- Use the **Hypothesis Form** on page 223 to make brief notes after reviewing the pollutant pathway data.
- Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.)
- Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed. (See *Section 8* for guidance on hiring outside assistance.)

COLLECTING SOURCE INFORMATION

Strategies	Tools
Conduct onsite inspection	▪ Pollutant and Source Inventory ▪ Chemical Inventory
Talk with building occupants, facilities staff, and contractors	▪ Pollutant and Source Inventory ▪ Chemical Inventory

Sample Form

Pollutant and Source Inventory Form

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment.

Source Category	Checked	Needs Attention	Location	Comments
SOURCES OUTSIDE THE BUILDING				
Contaminated Ambient Air				
Pollen, dust				
Industrial contaminants				
General vehicular contaminants				

Sample Form

Chemical Inventory

The inventory should include chemicals stored or used in the building for cleaning, maintenance, operations, and pest control.

Date	Chemical/ Brand Name	Use	Storage Location(s)	MSDS on File?

SEE COMPLETE FORMS PAGES 213 AND 221

COLLECTING INFORMATION ON POLLUTANT SOURCES

Throughout the investigation, the building investigator will try to identify pollutant sources that may be causing the occupant complaints. Any public or commercial building is likely to contain a number of sources that produce odors, contaminants, or both. The investigator's task is to identify the source(s) that may be responsible for the complaint(s).

The area included in the pollutant source inventory should be defined by the investigator's understanding of the building's architectural and mechanical layout and pollutant pathways. Common sense will help to differentiate unusual sources (e.g., spills, strong odors from new furnishings or equipment) from those that are normally found within or near the building.

Remember that very few sources of indoor air contaminants are both continuous and constant in volume over time. Pollutant concentrations often vary in strength over time, and may not be evident at the time of the site visit. Some sources are subtle and might only be noticed by a trained investigator. As the investigation progresses, the inventory of pollutant sources may need to be revised by expanding the definition of the complaint area or examining specific locations more closely (e.g., under various operating conditions).

Onsite Inspection

Depending upon the nature of the complaint, the investigator may find some of the following activities to be useful. This list is not intended to be complete.

Inventory outdoor sources

- Examine the area around the outdoor air intake for unsanitary conditions, standing water, or nearby pollutant sources such as exhaust vents or motor vehicles.
- Observe patterns of traffic, construction activity, and other potential sources in the neighborhood of the building.

- Inquire about outdoor ambient air problems in the area. (This information may be available from your local Health Department.)
- Observe soil gas entry points.

Inventory equipment sources

- Review non-HVAC equipment, particularly large office equipment such as engineering drawing reproduction machines and wet-process copiers. Learn about usage patterns and identify items that are not equipped with local exhaust.
- Review biocides, water treatment used on HVAC equipment.

Review building components and furnishings

- Check drain traps to make sure they are not dry.
- Identify areas of excessive dust and/or deteriorated furnishings.
- Identify areas of soil or water damage.
- Identify locations of new furnishings.

Inventory other potential sources

- Identify special use areas such as smoking lounges, laboratories, print shops.
- Identify areas where remodeling, repair, or redecorating activities are in progress or recently completed. Check procedures being used to isolate demolition dust, paint fumes, and other contaminants related to the process.
- Inventory cleaning materials used in the building.

(See *Section 4* for another discussion of problem indicators and common problems that may become obvious during a walkthrough of the building.)

The **Pollutant and Source Inventory** can be used to record your observations. The **Chemical Inventory** form is intended to serve as a record of materials such as solvents, biocides, pesticides, and cleaning compounds that may require special care in storage and handling. Material Safety Data Sheets (MSDSs) should be collected on these materials whenever possible. (See *Section 4* for further discussion of MSDSs.) Portions of both forms are shown on the poopsite page; the complete form is included in Tab V.

Talk With Building Occupants and Facility Staff

Building occupants and facility staff can provide valuable information about the location and timing of activities that produce odors or contaminants (e.g., smoking, cooking, housekeeping, maintenance). They may also suggest explanations for the IAQ problem that can help in the development of hypotheses. Facility staff and outside contractors (e.g., persons involved in housekeeping, pest control, or remodeling) should be interviewed or asked to provide a current list of materials, procedures, and schedules used for cleaning and pest control.

It may be useful to discuss the following items with building occupants:

Inventory activities

- Review smoking policy (and actual practice; cleaning staff may know where smoking occurs in violation of policy, especially in private offices).
- Identify areas of overcrowding.
- Review products used for housekeeping, maintenance, and pest control and the schedules of their use.
- Inquire about housekeeping schedules and procedures.
- Identify supply storage areas and check for well-sealed containers and proper ventilation.

Discuss incidents that could be sources

- Inquire about prior and neighboring uses of land (e.g., landfills, underground fuel tanks).
- Inquire about events such as spills, fires, or leaks.
- If such events have occurred, learn what remedial actions were taken to clean up after the incidents and to prevent their recurrence.

PATTERNS	SUGGESTIONS
Location(s) of sources	■ Compare locations of sources to locations of complaint(s). ■ Identify pathways linking potential sources to the complaint area. ■ Revise definition of complaint area if necessary.
Timing of emissions	■ Note whether the sources emit on a continuous or intermittent basis. ■ Compare the timing of emissions to the timing of complaints. ■ Identify occasions when the source is likely to be strongest. ■ Determine whether pathways between the source(s) and the complaint location could account for the occasions of complaints.

WHAT DO YOU KNOW SO FAR?

- Use the **Hypothesis Form** on page 223 to make brief notes after reviewing the pollutant source data.
- Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.)
- Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed. (See *Section 8* for guidance on hiring outside assistance.)

USING POLLUTANT SOURCE DATA

If a strong pollutant source is identified in the immediate vicinity of the complaint, a simple test (e.g., sealing, covering, or removing the source) can sometimes reveal whether or not it is the cause of the IAQ problem. If a number of potential sources have been found in and around the complaint area, other data (e.g., the pattern of symptoms, the HVAC system design and operation, and pollutant pathways) may be needed in order to determine which source(s), if any, may be related to the complaint.

Strategies for Using Source Information

- Identify patterns linking emissions to complaints
- Evaluate unrelated sources

Identify Patterns Linking Emissions to Complaints

Look for patterns linking emissions from potential sources to the IAQ complaints.

Evaluate Unrelated Sources

Evaluate sources that appear unrelated to the complaints. It is not unusual to identify potential contaminant sources that are unrelated to the present IAQ complaint (i.e., either the location of the source, the timing of emissions, or both fit poorly with the pattern of complaints). These should be prioritized for remedial work according to their potential for causing health problems or complaints in the future.

A detailed study of pollutants and sources may involve an engineering evaluation of equipment that is releasing IAQ contaminants, diagnostic sampling to assess sources in operation, or other measurements. These may require skills or instruments that are not available in-house.

SAMPLING AIR FOR CONTAMINANTS AND INDICATORS

Although air sampling might seem to be the logical response to an air quality problem, such an approach may not be required to solve the problem and can even be misleading. Air sampling should not be undertaken until some or all of the other investigative activities mentioned previously have been used to collect considerable information. Before beginning to take air samples, investigators should develop a sampling strategy that is based on a comprehensive understanding of how the building operates, the nature of the complaints, and a plan for interpreting the results.

It may be desirable to take certain routine air quality measurements during an investigation to obtain a “snapshot” of current conditions. These tests should be limited to those that are indicative of very common IAQ concerns such as temperature, relative humidity, air movement, or carbon dioxide (CO_2). Unusual readings may or may not indicate a problem, and should always be interpreted in perspective, based upon site-specific conditions.

Measurement of specific chemical or biological contaminants can be very expensive. Before expending time and money to obtain measurements of indoor air pollutants, you must decide:

- how the results will be used (e.g., comparison to standards or guidelines, comparison to levels in complaint-free areas)
- what substances(s) should be measured
- where to take samples
- when to take samples
- what sampling and analysis method to use so that the results provide useful information

It is often worthwhile for building staff to develop skills in making temperature, humidity, airflow, and CO_2 measurements and assessing patterns of air movement (e.g., using chemical smoke). *Appendix A* provides a brief introduction to ventilation and thermal measurement strategies and to methods of sampling for specific air contaminants.

How Will the Results Be Used?

Although air sampling will generate numbers, it will not necessarily help resolve the IAQ problem. Many IAQ complaints are resolved without sampling or with inconclusive sampling results.

The design of an air sampling strategy should fit the intended use of the measurements. Potential uses of indoor air measurements include:

1. Comparing different areas of the building or comparing indoor to outdoor conditions in order to:

   Confirm that a control approach has the desired effect of reducing pollutant concentrations or improving ventilation

   Establish baseline conditions so that they can be compared to concentrations at other times or locations, such as

   - concentrations in outdoor air
   - concentrations in areas where no symptoms are reported
   - expected "background" range for typical buildings without perceived IAQ problems

Test a hypothesis about the source of the problem, such as

- checking emissions from a piece of equipment

2. Testing for "indicator" compounds associated with particular types of building conditions:

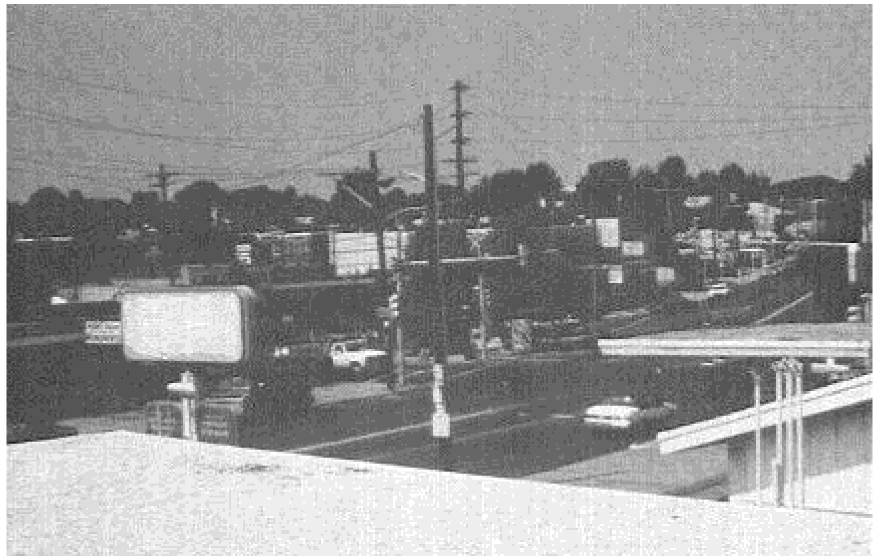
   Peak carbon dioxide (CO_2) concentrations over 1000 ppm (parts per million) are an indicator of underventilation

   Carbon monoxide (CO) over several ppm indicates inappropriate presence of combustion by-products (which may also account for high CO_2 readings)

3. Comparing measured concentrations to guidelines or standards

   Occupational exposure standards and guidelines, such as

   - OSHA PELs (Occupational Safety and Health Administration's Permissible Exposure Limits)
   - NIOSH RELs (National Institute for Occupational Safety and Health's Recommended Exposure Limits)
   - ACGIH TLVs (American Conference of Governmental Industrial Hygienists' Threshold Limit Values)



Occupants in this one-story office building were complaining of intermittent gasoline odors. Exhausts from underground gasoline storage tank vent pipes (visible in the lower right portion of this photograph) were being drawn into the office building through outdoor air intakes on this roof. The gasoline storage tanks belonged to an adjacent service station.

It is prudent to begin a program of chemical sampling only if symptoms or observations strongly suggest that a specific pollutant or a specific source may be the cause of the complaint and if sampling results are important in determining an appropriate corrective action.

Public health guidelines for specific pollutants

- EPA National Ambient Air Quality Standards
- World Health Organization Air Quality Guidelines
- Canadian Exposure Guidelines for Residential Air Quality

There are no widely accepted procedures to define whether IAQ test results are acceptable. Extreme caution must be used in comparing contaminant concentrations to existing occupational standards and guidelines. Although a contaminant concentration above those guidelines is a clear problem indicator, occupants may still experience health and comfort problems at concentrations well within those guidelines. **It is extremely rare for occupational standards to be exceeded — or even approached — in public and commercial buildings, including those experiencing indoor air quality problems.**

Where specific exposure problems are suspected, more detailed diagnostic testing may be needed to locate or understand major sources, confirm the exposure, and to develop appropriate remedial actions. For example, the control of microbial or pesticide contamination may involve surface or bulk sampling. (Surface sampling involves wiping a measured surface area and analyzing the swab to see what organisms are present, while bulk sampling involves analyzing a sample of suspect material.) Specialized skills, experience, and equipment may be needed to obtain, analyze, and interpret such measurements.

What Substance(s) Should Be Measured?

Measurement of "indicator" compounds such as CO_2 or CO can be a cost-effective strategy. Such measurements can help the investigator understand the nature of the problem and define the complaint area.

Air sampling for specific pollutants works best as an investigative tool when it is combined with other types of information-gathering. It is prudent to begin a program of chemical sampling only if symptoms or observations strongly suggest that a specific pollutant or a specific source may be the cause of the complaint and if sampling results are important in determining an appropriate corrective action.

Where Should Air Samples Be Taken?

The identified problem area is an obvious site for air sampling. Measurements taken outdoors and in a control location (e.g., a complaint-free area of the building) are helpful in interpreting results from the complaint area.

The conditions experienced by building occupants are best simulated by sampling air from the "breathing zone" away from the influence of any particular individual. However, if an individual sits at a desk all day (except for brief periods), samplers placed on the desk when the individual is elsewhere can provide a good estimate of that person's exposure.

There are several ways to locate sampling sites for an IAQ investigation. One approach first divides the building into homogeneous areas based on key factors identified in the building inspection and interviews. Examples of how a building might be divided include:

- control zones (e.g., individual rooms)
- types of HVAC zones (e.g., interior vs. perimeter)
- complaint vs. non-complaint areas
- relationship to major sources (e.g., spaces directly, indirectly, or not impacted by smoking areas)
- complaint types

Test sites can then be selected to represent complaints, controls, and potential sources with a reasonable number of samples.

When Should Indoor Air Samples Be Taken?

Samples may be designed to obtain "worst-case" conditions, such as measurements during periods of maximum equipment emissions, minimum ventilation, or disturbance of contaminated surfaces. Worst-case sample results can be very helpful in characterizing maximum concentrations to which occupants are exposed and identifying sources for corrective measures.

It is also helpful to obtain samples during average or typical conditions as a basis of comparison. It may, however, be difficult to know what conditions are typical. Research shows that exposure to some pollutants may vary dramatically as building conditions change. Devices that allow continuous measurements of key variables can be helpful.

Symptoms or odors that only occur occasionally will not generally be seen during the IAQ investigation. Air samples should not be taken if an incident is not occurring, unless the purpose of the sample is to establish a baseline for future comparisons.

One approach to intermittent IAQ problems is for the IAQ investigator to ask appropriate building staff or other occupants to document changes over time using day-to-day records such as the **Occupant Diary** and **Log of Activities and System Operation**. When an odor episode does occur, the building engineer could inspect the air handler and intake area while another staff member documents the status of several potential sources.

Another strategy is to manipulate building conditions to create worst-case conditions during the building investigation (e.g., arrange for the trash truck to idle at the loading dock or close outdoor air dampers to minimum settings). Chemical smoke and tracer gases can be used to assess where emissions may travel under various building conditions. (Such strategies should be carried out in ways that minimize occupant exposure.)

What Sampling and Analysis Method Should Be Used?

Take care to select appropriate measurement techniques and to provide interpretations so that the results provide useful information. *Appendix A* provides guidance on measurement techniques that are commonly used in IAQ investigations.

COMPLAINTS DUE TO CONDITIONS OTHER THAN POOR AIR QUALITY

Complaints that initially seem to be linked to thermal discomfort, underventilation, or indoor air pollutants may actually be caused or complicated by factors such as:

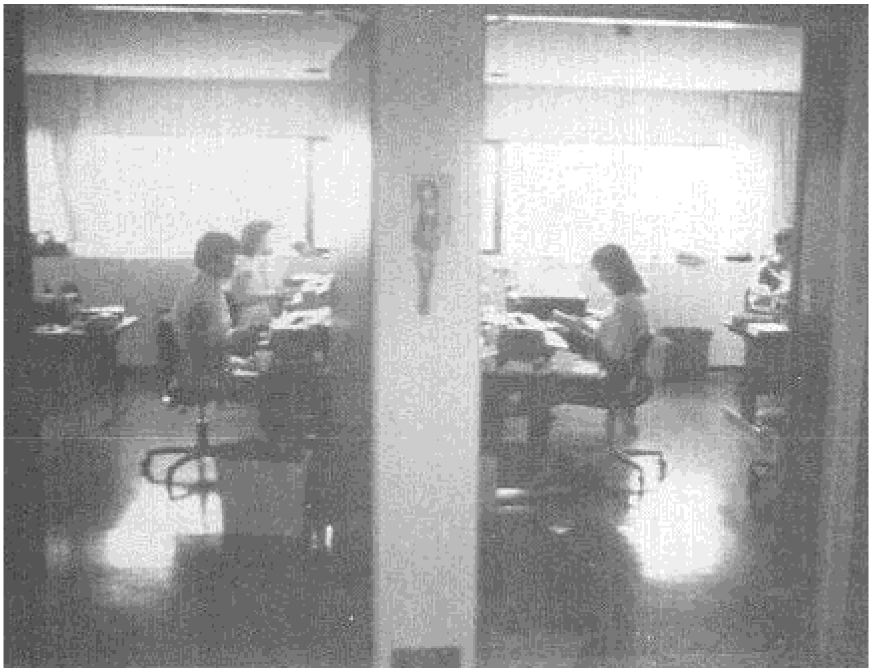
- environmental stressors (e.g., lighting, noise, vibration)
- ergonomic stressors
- job-related psychosocial (human relations) stressors

The following briefly discusses each of these three kinds of stressors. Investigators should bear in mind that complaints produced by these stressors are sometimes mistakenly blamed on contaminated air. To complicate matters, such stressors also can produce a heightened sensitivity to poor indoor air quality. Thus, even when specific stressors are obvious, the investigator should not assume that they are the only reason for the complaints.

Investigators should bear in mind that complaints produced by these stressors are sometimes mistakenly blamed on contaminated air. To complicate matters, such stressors also can produce a heightened sensitivity to poor indoor air quality.

Lighting

Stresses from inadequate or poorly designed lighting (e.g., glare, flicker, poor illumination of work surfaces) can produce symptoms such as eyestrain and headaches. Lack of natural sunlight can also be a source of stress. These complaints are sometimes mistakenly interpreted as signs of poor indoor air quality. Lighting problems may be evident in large areas or localized in particular workspaces.



The glare from the windows was causing a variety of occupant complaints in this building and was disrupting the workers' ability to use the video display terminals. Complaints such as headaches are sometimes incorrectly blamed on poor indoor air quality.

Noise

Noisy surroundings can reduce the ability to concentrate and produce stress-related symptoms such as headaches. Noise can also contribute to job dissatisfaction, particularly if the problem is caused by overcrowding or other factors likely to produce a sense of substandard work conditions.

The ear gets used to sounds quickly, so it is possible for a complainant to be unaware of a constant or regular sound. Investigators should recognize that noise can be a source of stress, even if it is not reported as a problem and is within current industrial exposure criteria (which are designed primarily to prevent hearing loss).

Vibration

Low-frequency vibration is another source of stress that may go unreported by building occupants or become confused with pollutant problems. Vibration can be caused by nearby machinery or movement of the building as a whole; motion sickness has been reported in some high rise buildings that sway in the wind.

Ergonomic Stressors

Fatigue, circulatory problems, and other physical problems can be produced by furniture that is mismatched to the task, such as chairs that are the wrong height for computer terminals. If IAQ investigators inquire about whether new furniture has recently been installed in the problem area (to determine if the furniture could be contributing to increased contaminant levels), they should also ask about whether the occupant finds the furniture comfortable.

Job-related Psychosocial Stressors

It is well documented that various job-related psychosocial conditions can produce symptoms in workers. Excessive workload and work pressure are easily recognized job stressors. Lack of clarity about what is expected of the worker (role ambiguity) and the presence of conflicting expectations (role conflict) are also commonly encountered stressors in modern organizations. Poor interpersonal relations, management styles that allow little participation in decision-making, and factors related to career development are also thought to be potentially stressful.

FORMING AND TESTING HYPOTHESES

As the building investigation progresses, you should be developing one or more hypotheses that could explain the occupant complaints. The investigation can then be shaped to collect information that will either support or refute your hypotheses.

The **Hypothesis Form** on the opposite page is designed to pull together the separate pieces of information that have been collected by summarizing the results of the investigation. More pages can be added if desired, but the form is designed for brief notes that can be scanned easily. As you review the information, write down any explanation(s) for the IAQ problem that make sense, and think about how the pieces of the puzzle fit together when building conditions are compared to occupant complaints.

Is all (or most) of your information consistent with your hypothesis? If not, is there a reasonable explanation for the inconsistencies? A different hypothesis might provide a better fit with your information.

You may find that there are several IAQ problems (e.g., underventilation in one zone, a strong contaminant source in another room). If you have discovered potential IAQ problems that do not appear related to the original complaint, they can be prioritized and corrected as time and funding permit.

Think of ways to test your hypotheses. You may want to change ventilation rates, change the pressure relationship between spaces, cover or remove suspected sources, seal pathways, or temporarily relocate affected individuals. If your manipulations can reduce occupant complaints, you have found a reasonable hypothesis. Sometimes it is not possible (or not practical) to manipulate important factors. You can also test your hypothesis by seeing how accurately you can predict changes in building conditions (e.g., as outdoor temperature changes).

If you are having difficulty developing hypotheses, review the information you have collected and the suggestions about how to use that information. For suggestions on using occupant complaint data, see pages 53-57; on using HVAC system information, see pages 62-67; on using pollutant pathway information, see pages 70-71; on using pollutant/source inventory data, see page 74; on using air sampling information, see pages 75-76.

The changes that are made during hypothesis testing may offer a practical solution to the IAQ problem, or may be only temporary measures. The mitigation chapter presents a variety of approaches that have been used in correcting some selected categories of IAQ problems and discusses how to evaluate those strategies.

SEE COMPLETE FORM PAGE 223

Sample Form
Hypothesis Form

Complaint Area (may be revised as the investigation progresses):

____

____

Complaints (e.g., summarize patterns of timing, location, people affected):

____

____

HVAC: Does the ventilation system appear to provide adequate air, efficiently distributed to meet occupant needs in the complaint area? If not, what problems do you see?

____

____

Pathways: What pathways and driving forces connect the complaint area to locations of potential sources?

____

____

Mitigating IAQ Problems

7

Over the years many types of mitigation (correction) strategies have been implemented to solve indoor air quality problems. The purpose of this section is to provide an understanding of basic approaches to mitigation and the various solutions that can be effective in treating commonly-encountered IAQ problems. It is not intended to provide detailed instructions for using each type of mitigation approach but rather to give guidance in selecting a mitigation strategy and in judging proposals from in-house staff or outside consultants.

Mitigation of indoor air quality problems may require the involvement of building management and staff representing such areas of responsibility as:

- facility operation and maintenance
- housekeeping
- shipping and receiving
- purchasing
- policymaking
- staff training

Successful mitigation of IAQ problems also requires the cooperation of other building occupants, including the employees of building tenants. Occupants must be educated about the cause(s) of the IAQ problems and about actions that must be taken or avoided to prevent a recurrence of the problems.

BACKGROUND: CONTROLLING INDOOR AIR PROBLEMS

Section 2 introduced the idea that indoor air quality problems result from interactions between contaminant source, building site, building structure, activities within the building, mechanical equipment, climate, and occupants. Efforts to control indoor air contaminants change the relationships between these factors. There are many ways that people can intervene in these relationships to prevent or control indoor air contaminant problems. Control strategies can be categorized as:

- source control
- ventilation
- air cleaning
- exposure control

Successful mitigation often involves a combination of these strategies. Possible remedies for the other environmental stressors discussed in *Section 6* are discussed briefly below.

Source Control

All efforts to prevent or correct IAQ problems should include an effort to identify and control pollutant sources. Source control is generally the most cost effective approach to mitigating IAQ problems in which point sources of contaminants can be identified. In the case of a strong source, source control may be the only solution that will work.

The following are categories and examples of source control:

Remove or reduce the source

- prohibit smoking indoors or limit smoking to areas from which air is exhausted, not recirculated (NIOSH regards smoking areas as an interim solution)
- relocate contaminant-producing equipment to an unoccupied, better ventilated, or exhaust-only ventilated space
- select products which produce fewer or less potent contaminants while maintaining adequate safety and efficacy

- modify other occupant activities

Seal or cover the source

- improve storage of materials that produce contaminants
- seal surfaces of building materials that emit VOCs such as formaldehyde

Modify the environment

- after cleaning and disinfecting an area that is contaminated by fungal or bacterial growth, control humidity to make conditions inhospitable for regrowth

Source removal or reduction can sometimes be accomplished by a one-time effort such as thorough cleaning of a spill. In other cases, it requires an ongoing process, such as establishing and enforcing a non-smoking policy.

Sealing or covering the source can be a solution in some cases; application of a barrier over formaldehyde-emitting building materials is an example. Sealing may also involve educating staff or building occupants about the contaminant-producing features of materials and supplies and inspecting storage areas to ensure that containers are properly covered.

In some cases, modification of the environment is necessary for effective mitigation. If the indoor air problem arises from microbiological contaminants, for example, disinfection of the affected area may not eliminate the problem. Regrowth of microbiologicals could occur unless humidity control or other steps, such as adding insulation to prevent surface condensation, are taken to make the environment inhospitable to microbiologicals.

Ventilation

Ventilation modification is often used to correct or prevent indoor air quality problems. This approach can be effective either where buildings are underventilated or where a specific contaminant source cannot be identified. Ventilation can be used to control indoor air contaminants by:

Diluting contaminants with outdoor air

- increase the total quantity of supply air (including outdoor air)
- increase the proportion of outdoor air to total air
- improve air distribution

Isolating or removing contaminants by controlling air pressure relationships

- install effective local exhaust at the location of the source
- avoid recirculation of air that contains contaminants
- locate occupants near supply diffusers and sources near exhaust registers
- use air-tightening techniques to maintain pressure differentials and eliminate pollutant pathways
- make sure that doors are closed where necessary to separate zones

Diluting contaminants by increasing the flow of outdoor air can be accomplished by increasing the total supply airflow in the complaint area (e.g., opening supply diffusers, adjusting dampers) or at the air handling unit, (e.g., cleaning the filter on the supply fan). An alternative is to increase the proportion of outdoor air (e.g., adjusting the outdoor air intake damper, installing minimum stops on variable air volume (VAV) boxes so that they satisfy the outdoor air requirements of ASHRAE 62-1989).

Studies have shown that increasing ventilation rates to meet ASHRAE Standard 62-1989 (e.g., from 5 to 15 or 20 cfm/person) does not necessarily significantly increase the total annual energy consumption. The increase appears to be less than 5% in typical commercial buildings. The cost of ventilation is generally overshadowed by other operating costs, such as lighting. Further, improved maintenance can produce energy savings to balance the costs that might otherwise result from increased ventilation.

The cost of modifying an existing HVAC system to condition additional outdoor air can vary widely depending upon the specific situation. In some buildings, HVAC equipment may not have sufficient capacity to allow successful mitigation using this approach. Original equipment is often oversized so that it can be adjusted to handle the increased load, but in some cases additional capacity is required.

Most ventilation deficiencies appear to be linked to inadequate quantities of outdoor air. However, inadequate distribution of ventilation air can also produce IAQ problems. Diffusers should be properly selected, located, installed, and maintained so that supply air is evenly distributed and blends thoroughly with room air in the breathing zone. Short-circuiting occurs when clean supply air is drawn into the return air plenum before it has mixed with the dirtier room air and therefore fails to dilute contaminants. Mixing problems can be aggravated by temperature stratification. Stratification can occur, for example, in a space with high ceilings in which ceiling-mounted supply diffusers distribute heated air.

Note the side effects of increased ventilation:

- mitigation by increasing the circulation of outdoor air requires good outdoor air quality
- increased supply air at the problem location might mean less supply air in other areas
- increased total air in the system and increased outdoor air will both tend to increase energy consumption and may require increased equipment capacity
- any approach which affects airflow in the building can change pressure differences between rooms (or zones) and between indoors and outdoors, and might lead to increased infiltration of unconditioned outdoor air
- increasing air in a VAV system may overcool an area to the extent that terminal reheat units are needed

Ventilation equipment can be used **to isolate or contain contaminants by controlling pressure relationships.** If the contaminant source has been identified, this strategy can be more effective than dilution. Techniques for controlling air pressure relationships range from adjustment of dampers to installation of local exhaust.

Using local exhaust confines the spread of contaminants by capturing them near the source and exhausting them to the outdoors. It also dilutes the contaminant by drawing cleaner air from surrounding areas into the exhaust airstream. If there are return grilles in a room equipped with local exhaust, the local exhaust should exert enough suction to prevent recirculation of contaminants. Properly designed and installed local exhaust results in far lower contaminant levels in the building than could be accomplished by a general increase in dilution ventilation, with the added benefit of costing less.

Note that replacement air must be able to flow freely into the area from which the exhaust air is being drawn. It may be necessary to add door or wall louvers in order to provide a path for the make-up air. (Make sure that this action does not violate fire codes.)

Correct identification of the pollutant source and installation of the local exhaust is critically important. For example, an improperly designed local exhaust can draw other contaminants through the occupied space and make the problem worse.

The physical layout of grilles and diffusers relative to room occupants and pollutant sources can be important. If supply diffusers are all at one end of a room and returns are all at the other end, the people located near the supplies may be provided with relatively clean air while those located near the returns breathe air that has already picked up contaminants from all the sources in the room that are not served by local exhaust.

Elimination of pollutant pathways by air sealing (e.g., caulking cracks, closing holes) is an approach that can increase the effectiveness of other control techniques. It can be a difficult technique to implement because of hidden pathways (e.g., above drop ceilings, under raised flooring against brick or block walls). However, it can have other benefits such as energy savings and more effective pest control (by eliminating paths used by vermin).

Air Cleaning

The third IAQ control strategy is to clean the air. Air cleaning is usually most effective when used in conjunction with either source control or ventilation; however, it may be the only approach when the source of pollution is outside of the building. Most air cleaning in large buildings is aimed primarily at preventing contaminant buildup in HVAC equipment and enhancing equipment efficiency.

Air cleaning equipment intended to provide better indoor air quality for occupants must be properly selected and designed for the particular pollutants of interest (for example, gaseous contaminants can be removed only by gas sorption). Once installed, the equipment requires regular maintenance in order to ensure good performance; otherwise it may become a major pollutant source in itself. This maintenance requirement should be borne in mind if an air cleaning system involving a large number of units is under consideration for a large building. If room units are used, the installation should be designed for proper air recirculation.

There are four technologies that remove contaminants from the air:

- particulate filtration
- electrostatic precipitation
- negative ion generation
- gas sorption

The first three approaches are designed to remove particulates, while the fourth is designed to remove gases.

Particulate filtration removes suspended liquid or solid materials whose size, shape and mass allow them to remain airborne for the air velocity conditions present. Filters are available in a range of efficiencies, with higher efficiency indicating removal of a greater proportion of particles and of smaller particles. Moving to medium efficiency pleated filters is advisable to improve IAQ and increase protection for equipment. However, the higher the efficiency of the filter, the more it will increase the pressure drop within the air distribution system and reduce total airflow (unless other adjustments are made to compensate). It is important to select an appropriate filter for the specific application and to make sure that the HVAC system will continue to perform as designed. Filters are rated by different standards (e.g., arrestance and dust spot) which measure different aspects of performance.

Electrostatic precipitation is another type of particulate control. It uses the attraction of charged particles to oppositely charged surfaces to collect airborne par-ticulates. In this process, the particles are charged by ionizing the air with an electric field. The charged particles are then col-lected by a strong electric field generated between oppositely-charged electrodes. This provides relatively high efficiency filtration of small respirable particles at low air pressure losses.

Electrostatic precipitators may be installed in air distribution equipment or in specific usage areas. As with other filters, they must be serviced regularly. Note, however, that electrostatic precipitators produce some ozone. Because ozone is harmful at elevated levels, EPA has set standards for ozone concentrations in outdoor air, and NIOSH and OSHA have established guidelines and standards, respectively, for ozone in indoor air. The amount of ozone emitted from electrostatic precipitators varies from model to model.

Negative ion generators use static charges to remove particles from the indoor air. When the particles become charged, they are attracted to surfaces such as walls, floors, table tops, draperies, and occupants. Some designs include collectors to attract the charged particles back to the unit. Negative ion generators are not available for installation in ductwork, but are sold as portable or ceiling-mounted units. As with electrostatic precipitators, negative ion generators may produce ozone, either inten-tionally or as a by-product of use.

Gas sorption is used to control compounds that behave as gases rather than as particles (e.g., gaseous contaminants such as formaldehyde, sulfur dioxide, ozone, and oxides of nitrogen). Gas sorption involves one or more of the following processes with the sorption material (e.g., activated carbon, chemically treated active clays): a chemical reaction between the pollutant and the sorbent, a binding of the pollutant and the sorbent, or diffusion of the contaminant from areas of higher concentration to areas of lower concentration. Gas sorption units are installed as part of the air distribution system. Each type of sorption material performs differently with different gases. Gas sorption is not effective for removing carbon monoxide. There are no standards for rating the performance of gaseous air cleaners, making the design and evaluation of such systems problematic. Operating expenses of these units can be quite high, and the units may not be effective if there is a strong source nearby.

Exposure Control

Exposure control is an administrative approach to mitigation that uses behavioral methods, such as:

Scheduling contaminant-producing activities to avoid complaints

- schedule contaminant-producing activities to occur during unoccupied periods
- notify susceptible individuals about upcoming events (e.g., roofing, pesticide application) so that they can avoid contact with the contaminants

Scheduling contaminant-producing activities for unoccupied periods whenever possible is simple common sense. It may be the best way to limit complaints about activities (such as roofing or demolition) which unavoidably produce odors or dust.

Relocating susceptible individuals

- move susceptible individuals away from the area where they experience symptoms

Controlling exposure by relocating susceptible individuals may be the only practical approach in a limited number of cases, but it is probably the least desirable option and should be used only when all other strategies are ineffective in resolving complaints.

Remedies for Complaints Not Attributed to Poor Air Quality

Specific lighting deficiencies or localized sources of noise or vibration can sometimes be readily identified, and remedial action may be fairly straightforward (more or fewer lights on, adjustments for glare; relocating, replacing or acoustically insulating a noise or vibration source). Similarly, flagrant ergonomic stress or blatant psychosocial stress may be apparent even to an untrained observer.

In other cases, however, problems may be more subtle or solutions more complex. Since specialized knowledge, skills, and instrumentation are usually needed to evaluate lighting, noise, vibration, ergonomic stress, or psychosocial stress, such evaluations are generally best done by a qualified professional in that particular field.

Remedial actions for lighting, noise, and vibration problems might range from modifications of equipment or furnishings to renovation of the building. Ergonomic deficiencies may require furniture or equipment changes or different work practices. The solution to psychosocial problems may involve new management practices, job redesign, or resolution of underlying labor-management problems.

SAMPLE PROBLEMS AND SOLUTIONS

In the investigation section you were introduced to a variety of problems that are often found in buildings. This section presents fifteen categories of IAQ problems. Specific problem "examples" are given, followed by solutions" that have been used for that category of problem. Most of the problems presented here are common and do not have serious, life-threatening consequences. At the end of the section is a brief description of problems that can have severe health impacts. The basic correction principles that apply to these serious problems are similar to those used in less critical situations.

Reading these examples may help you to think about the best way to solve your indoor air quality problems. Remember that these are brief sketches, and apparent parallels to your building could be misleading. It is better to carry out a building investigation and learn the specific facts in your own case, rather than adopt a mitigation approach that might not be appropriate. Attempting to correct IAQ problems without understanding the cause of those problems can be both ineffective and expensive.

You will note that some solutions are simple and low-cost, while others are complex and expensive. Do not assume that each solution listed would be an effective treatment for all of the problems in its category.

The example problems and solutions are presented in the following sequence:

Problem #1: Outdoor air ventilation rate is too low

Problem #2: Overall ventilation rate is high enough, but poorly distributed and not sufficient in some areas

Problem #3: Contaminant enters building from outdoors

Problem #4: Occupant activities contribute to air contaminants or to comfort problems

Problem #5: HVAC system is a source of biological contaminants

Problem #6: HVAC system distributes contaminants

Problem #7: Non-HVAC equipment is a source or distribution mechanism for contaminants

Problem #8: Surface contamination due to poor sanitation or accidents

Problem #9: Mold and mildew growth due to moisture from condensation

Problem #10: Building materials and furnishings produce contaminants

Problem #11: Housekeeping or maintenance activities contribute to problems

Problem #12: Specialized use areas as sources of contaminants

Problem #13: Remodeling or repair activities produce problems

Problem #14: Combustion gases

Problem #15: Serious building-related illness

Problem #1:
Outdoor Air Ventilation Rate is Too Low

Examples

Routine odors from occupants and normal office activities result in problems (e.g., drowsiness, headaches, discomfort)

Measured outdoor air ventilation rates do not meet guidelines for outdoor air supply (e.g., design specifications, applicable codes, or ASHRAE 62-1989)

Peak CO_2 concentrations above 1000 ppm indicate inadequate ventilation

Corrosion of fan casing causes air bypassing and reduces airflow in system

Solutions

Open, adjust or repair air distribution system

- outdoor air intakes
- mixing and relief dampers
- supply diffusers
- fan casings

Increase outdoor air within the design capacity of

- air handler
- heating and air conditioning equipment
- distribution system

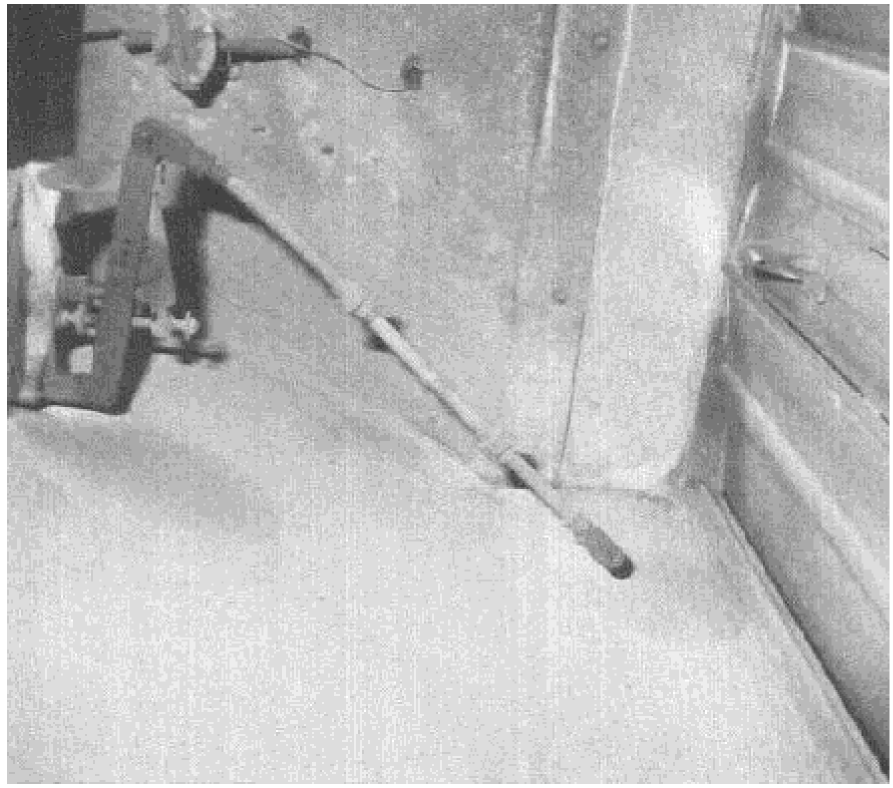
Modify components of the HVAC system as needed to allow increased outdoor air

(e.g., increase capacity of heating and cooling coils)

Design and install an updated ventilation system

Reduce the pollutant and/or thermal load on the HVAC system

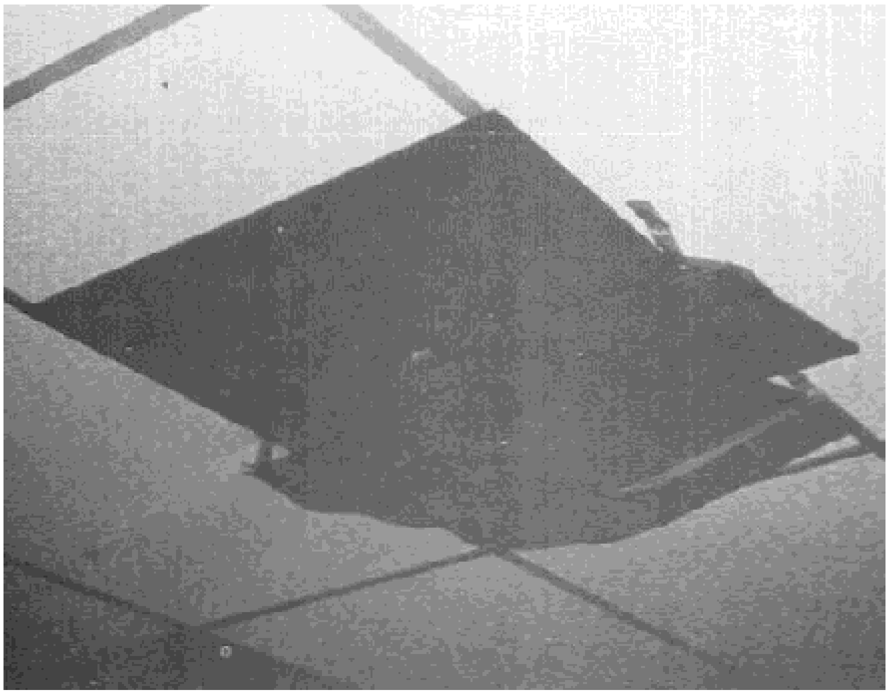
- reduce the occupant density: relocate some occupants to other spaces to redistribute the load on the ventilation system
- relocate or reduce usage of heat-generating equipment



Malfunctioning controls such as this broken damper linkage can virtually eliminate intake of outdoor air. Such problems may go undetected for years without a careful investigation of the HVAC system components.

Problem #2:

Overall Ventilation Rate Is High Enough, But Poorly Distributed and Not Sufficient in Some Areas



Complaining of discomfort, building occupants blocked air supply diffusers in their work areas. The HVAC system in this building was in poor condition and was not balanced.

Examples

Measured outdoor air meets guidelines at building air inlet, but there are zones where heat, routine odors from occupants, and normal office activities result in complaints
(e.g., drowsiness, headaches, comfort complaints)

Solutions

Open, adjust, or repair air distribution system

- supply diffusers
- return registers

Ensure proper air distribution

- balance the air handling system
- make sure that there is an air gap at tops and bottoms of partitions to prevent dead air space
- relocate supply and/or return diffusers to improve air distribution

Seal leaky ductwork

Remove obstructions from return air plenum

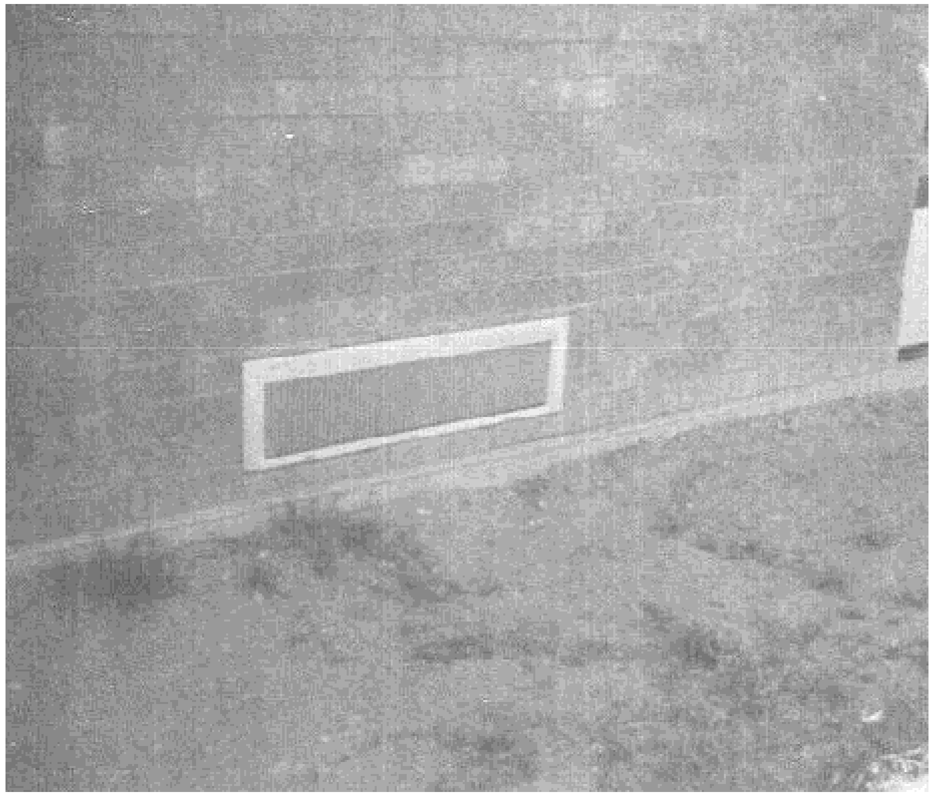
Control pressure relationships

- install local exhaust in problem areas and adjust HVAC system to provide adequate make-up air
- move occupants so that they are closer to supply diffusers
- relocate identified contaminant sources closer to exhaust intakes

Reduce source by limiting activities or equipment use that produce heat, odors, or contaminants

Design and install an appropriate ventilation system

Problem #3:
Contaminant Entering Building From Outdoors



Examples

Soil gases
(e.g., radon, gasoline from tanks, methane from landfills)

Contaminants from nearby activities
(e.g., roofing, dumpster, construction)

Outdoor air intake near source
(e.g., parking, loading dock, building exhaust)

Outdoor air contains pollutants or excess moisture
(e.g., cooling tower mist entrained in outdoor air intake)

Solutions

Remove the source, if it can be moved easily

- remove debris around outdoor air intake
- relocate dumpster

Reduce source (for example, shift time of activity to avoid occupied periods)

- painting, roofing, demolition
- housekeeping, pest control

Relocate elements of the ventilation system that contribute to entry of outdoor air contaminants

- separate outdoor air intakes from sources of odors, contaminants
- separate exhaust fan outlets from operable windows, doors, air intakes
- make rooftop exhaust outlets taller than intakes

Change air pressure relationships to control pollutant pathways

- install subslab depressurization to prevent entry of soil gas contaminants (radon, gases from landfills and underground tanks)
- pressurize the building interior relative to outdoors (this will not prevent contaminant entry at outdoor air intakes)
- close pollutant pathways (e.g., seal cracks and holes)

Add special equipment to HVAC system

- filtration equipment to remove pollutants (select to fit the situation)

For cosmetic reasons, air intakes are frequently located on rooftops or near the ground. This air intake could become a means of drawing lawn cuttings, vehicle exhaust, and pesticides into the building.

Problem #4:

Occupant Activities Contribute to Air Contaminants or to Comfort Problems

Personal equipment such as humidifiers brought in by building occupants can become a source of contaminants if not properly maintained. An effective communication strategy can help occupants to understand their role in causing indoor air quality problems and in correcting those problems.

Examples

Smoking

Special activities such as print shops, laboratories, kitchens

Interference with HVAC system operation:

- blockage of supply diffusers to eliminate drafts
- turning off exhaust fans to eliminate noise
- use of space heaters, desktop humidifiers to remedy local discomfort

(*Note:* While such interference can cause IAQ problems, it is often initiated in *response* to unresolved ventilation or temperature control problems.)

Solutions

Remove the source by eliminating the activity
(*Note:* This may require a combination of policy-setting and educational outreach.)

- smoking
- use of desktop humidifiers and other personal HVAC equipment
- unsupervised manipulation of HVAC system

Reduce the source

- select materials and processes which minimize release of contaminants while maintaining adequate safety and efficacy (e.g., solvents, art materials)

Install new or improved local exhaust to accommodate the activity, adjust HVAC system to ensure adequate make-up air, and verify effectiveness

- smoking lounge, storage areas which contain contaminant sources
- laboratory hoods, kitchen range hoods (venting to outdoors, not recirculating)

Problem #5:
HVAC System is a Source of Biological Contaminants

The HVAC system can act as a source of contaminants by providing a hospitable environment for the growth of microorganisms and by then distributing biologically-contaminated air within the building.

Examples

Surface contamination by molds (fungi), bacteria

- drain pans
- interior of ductwork
- air filters and filter media (collected debris).

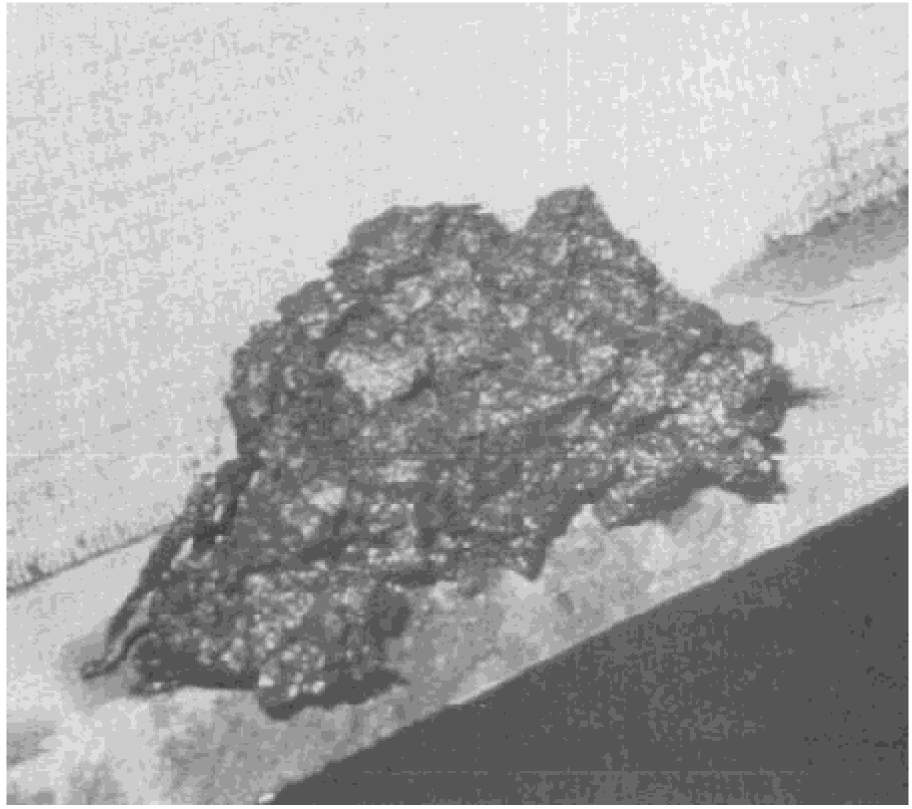
Solutions

Remove source by improving maintenance procedures

- inspect equipment for signs of corrosion, high humidity
- replace corroded parts
- clean drip pans, outdoor air intakes, other affected locations
- use biocides, disinfectants, and sanitizers with extreme caution and ensure that occupant exposure is minimized

(*Note:* See discussion of duct cleaning in *Appendix B.*)

Provide access to all the items that must be cleaned, drained, or replaced periodically



This blackish deposit was scraped from a poorly-maintained air handling unit drain pan. The pan contained nutrients caused by poor upstream filtration and stagnant water that fostered the growth of microbiological contaminants.

Problem #6:
HVAC System Distributes Contaminants

Standing water on a roof can cause water damage and potential mold growth sites inside the building as well as providing a breeding area for insects and microbiologicals such as Legionella. *The outside air intake (near the far left of this photograph) is located close to the standing water and could be drawing in insects and microbiological contaminants.*

Examples

Unfiltered air bypasses filters due to problems

- filter tracks are loose
- poorly-maintained filters sag when they become overloaded with dirt
- filters are the wrong size

Recirculation of air that contains dust or other contaminants

- system recirculates air from rooms containing pollutant sources
- return air plenum draws air from rooms that should be exhausted (e.g. janitor’s closets)
- return air plenums draw soil gases from interiors of block corridor walls that terminate above ceilings

Solutions

Modify air distribution system to minimize recirculation of contaminants

- provide local exhaust at point sources of contaminants, adjust HVAC system to provide adequate make-up air, and test to verify performance
- increase proportion of outdoor air
- seal unplanned openings into return air plenums and provide alternative local ventilation (adjust HVAC system to provide adequate make-up air and test to verify performance)

Improve housekeeping, pest control, occupant activities, and equipment use to minimize release of contaminants from all sources

Install improved filtration equipment to remove contaminants

Check filter tracks for any gaps

Problem #7:
Non-HVAC Equipment is a Source or Distribution Mechanism for Contaminants

This discussion pertains to medium- to large-scale pieces of equipment.

Examples

Non-HVAC equipment can produce contaminants, as in the case of:

- wet process copiers
- large dry process copiers
- engineering drawing reproduction machines

It can also distribute contaminants, as in the case of:

- elevators, which can act as pistons and draw contaminants from one floor to another

Solutions

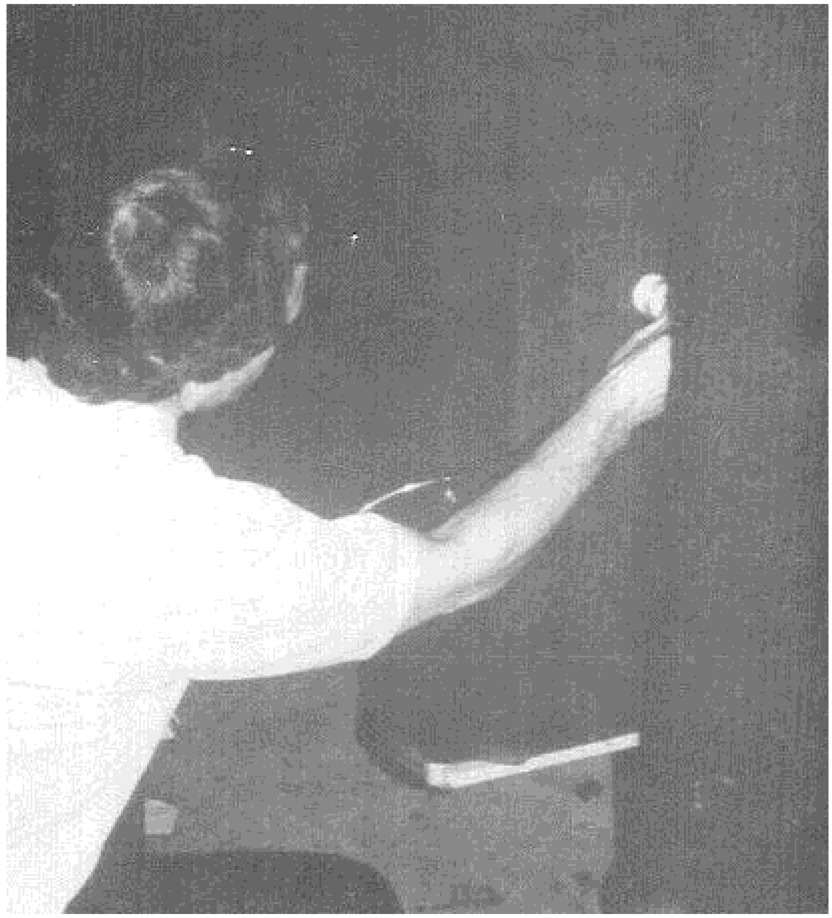
Install local exhaust near machines
(*Note:* Adjust HVAC system to provide adequate make-up air, and test to verify performance.)

Reschedule use to occur during periods of low occupancy

Remove source

- relocate occupants out of rooms that contain contaminant-generating equipment
- relocate equipment into special use areas equipped with effective exhaust ventilation (test to verify control of air pressure relationships)

Change air pressure relationships to prevent contaminants from entering elevator shaft



Sometimes there are unusual sources of indoor air quality problems. An inspection of the HVAC system revealed air filters covered with a graphite dust deposit from a broken elevator motor generator. The motor generator was repaired and corrections were made to prevent the crossover of ventilation air from the motor generator into the HVAC mechanical room.

Problem #8:

Surface Contamination Due to Poor Sanitation or Accidents

The carpet on this floor was flooded and an outbreak of humidifier fever occurred. To eliminate microbiologicals, the contaminated carpet was removed and new carpet was installed.

Examples

Biological contaminants result in allergies or other diseases

- fungal, viral, bacterial (whole organisms or spores)
- bird, insect, or rodent parts or droppings, hair, dander (in HVAC, crawlspace, building shell, or near outdoor air intakes)

Accidents

- spills of water, beverages, cleansers, paints, varnishes, mastics or specialized products (printing, chemical art supplies)
- fire damage: soot, odors, chemicals

Solutions

Clean

- HVAC system components
- some materials and furnishings (others may have to be discarded)

(*Note:* Use biocides, disinfectants, and sanitizers with caution and ensure that occupant exposure is minimized.)

Remove sources of microbiological contamination

- water-damaged carpet, furnishings, or building materials

Modify environment to prevent recurrence of microbiological growth

- improve HVAC system maintenance
- control humidity or surface temperatures to prevent condensation

Provide access to all items that require periodic maintenance

Use local exhaust where corrosive materials are stored

Adjust HVAC system to provide adequate make-up air, and test to verify performance

Problem #9:
Mold and Mildew Growth Due to Moisture from Condensation

This is a school crawlspace in which moisture should be controlled. The fungus is Fusarium, *some species of which are toxigenic and should not be inside. The spores were distributed by the air handler because the return plenum was open to the crawlspace.*

Examples

Interior surfaces of walls near thermal bridges
(e.g., uninsulated locations around structural members)

Carpeting on cold floors

Locations where high surface humidity promotes condensation

Solutions

Clean and disinfect to remove mold and mildew.
(*Note:* Follow up by taking actions to prevent recurrence of microbiological contamination. Use biocides, disinfectants, and sanitizers with caution and ensure that occupant exposure is minimized.)

Increase surface temperatures to treat locations that are subject to condensation

- insulate thermal bridges
- improve air distribution

Reduce moisture levels in locations that are subject to condensation

- repair leaks
- increase ventilation (in cases where outdoor air is cold and dry)
- dehumidify (in cases where outdoor air is warm and humid)

Dry carpet or other textiles promptly after steam cleaning
(*Note:* Increase ventilation to accelerate drying.)

Discard contaminated materials

Problem #10:
Building Materials and Furnishings Produce Contaminants

Low levels of contaminants are emitted from many of the building materials and furnishings in an office. Dust can accumulate on stacks of papers and open shelves. Depending on how they are cared for, plants potentially add moisture, soil microbiologicals, and pesticides.

Examples

Odors from newly installed carpets, furniture, wall coverings

Newly drycleaned drapes or other textiles

Solutions

Remove source with appropriate cleaning methods

- steam clean carpeting and upholstery, then dry quickly, ventilating to accelerate the drying process
- accept only fully dried, odorless drycleaned products

Encapsulate source

- seal surfaces of building materials that emit formaldehyde

Reduce source

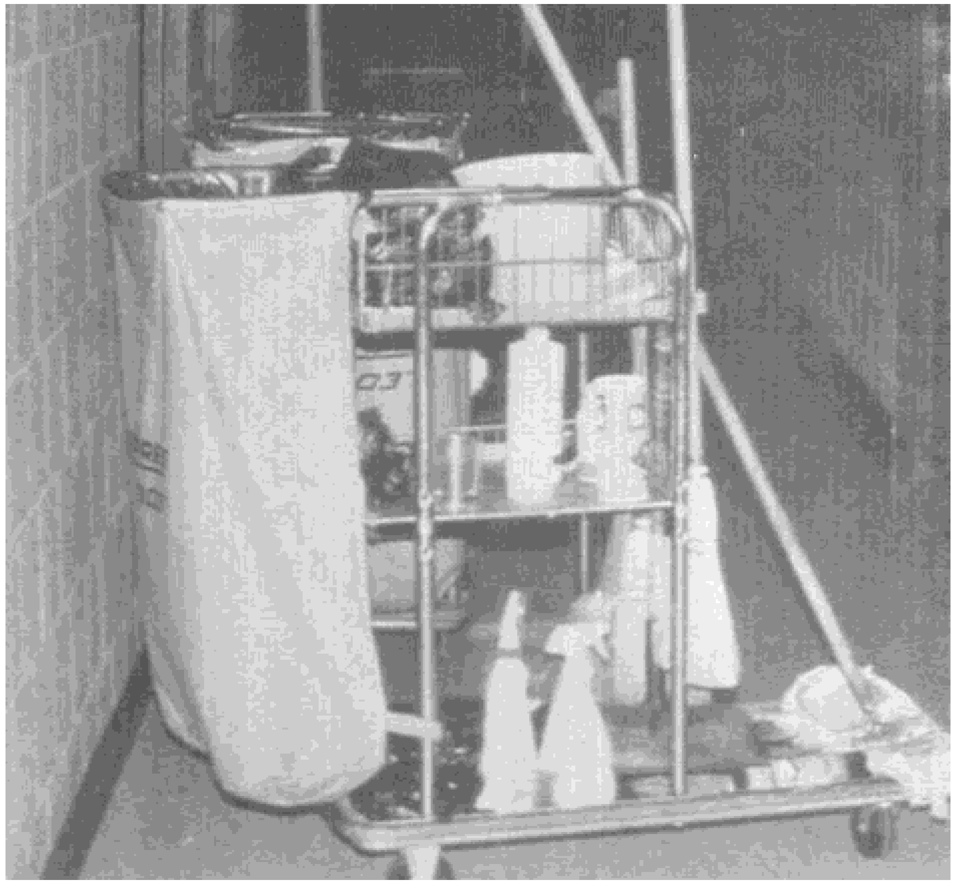
- schedule installation of carpet, furniture, and wall coverings to occur during periods when the building is unoccupied
- have supplier store new furnishings in a clean, dry, well-ventilated area until VOC outgassing has diminished

Increase outdoor air ventilation

- total air supplied
- proportion of fresh air

Remove the materials that are producing the emissions and replace with lower emission alternatives
(*Note:* Only limited information on emissions from materials is available at this time. Purchasers can request that suppliers provide emissions test data, but should use caution in interpreting the test results.)

Problem #11:
Housekeeping or Maintenance Activities Contribute to Problems



Indoor air quality problems can be caused by lack of adequate house-keeping practices. On the other hand, deodorizers, cleansers and other products can also produce odors and contaminants.

Examples

Cleaning products emit chemicals, odors

Particulates become airborne during cleaning (e.g., sweeping, vacuuming)

Contaminants are released from painting, caulking, lubricating

Frequency of maintenance is insufficient to eliminate contaminants

Solutions

Remove source by modifying standard procedures or frequency of maintenance (*Note:* Changing procedures may require a combination of policy-setting and training in IAQ impacts of staff activities.)

- improve storage practices
- shift time of painting, cleaning, pest control, other contaminant-producing activities to avoid occupied periods
- make maintenance easier by improving access to filters, coils, and other components

Reduce source

- select materials to minimize emissions of contaminants while maintaining adequate safety and efficacy
- use portable HEPA (high efficiency particulate arrestance") vacuums vs. low-efficiency paper-bag collectors

Use local exhaust

- on a temporary basis to remove contaminants from work areas
- as a permanent installation where contaminants are stored

Problem #12:

Specialized Use Areas as Sources of Contaminants

This chemical storage room should be maintained under negative pressure. Properly designed and maintained local exhaust will achieve the proper air pressure relationship with surrounding areas. Otherwise, such storage areas can be a source of occupant exposure to many airborne contaminants.

Examples

Food preparation
Art or print rooms
Laboratories

Solutions

Change pollutant pathway relationships

- run specialized use area under negative pressure relative to surrounding areas
- install local exhaust, adjust HVAC system to provide make-up air, and test to verify performance

Remove source by ceasing, relocating, or rescheduling incompatible activities

Reduce source by selecting materials to minimize emissions of contaminants while maintaining adequate safety and efficacy

Reduce source by using proper sealing and storage for materials that emit contaminants

Problem #13:
Remodeling or Repair Activities Produce Problems

Examples

Temporary activities produce odors and contaminants

- installation of new particleboard, partitions, carpet, or furnishings
- painting
- reroofing
- demolition

Existing HVAC system does not provide adequate ventilation for new occupancy or arrangement of space

Solutions

Modify ventilation to prevent recirculation of contaminants

- install temporary local exhaust in work area, adjust HVAC system to provide make-up air, and test to verify performance
- seal off returns in work area
- close outdoor air damper during re-roofing

Reduce source by scheduling work for unoccupied periods and keeping ventilation system in operation to remove odors and contaminants

Reduce source by careful materials selection and installation

- select materials to minimize emissions of contaminants while maintaining adequate safety and efficacy
- have supplier store new furnishings in a clean, dry, well-ventilated area until VOC outgassing has diminished
- request installation procedures (e.g., adhesives) that limit emissions of contaminants

Modify HVAC or wall partition layout if necessary

- partitions should not interrupt airflow
- relocate supply and return diffusers
- adjust supply and return air quantities
- adjust total air and/or outdoor air supply to serve new occupancy

Remodeling may involve many activities that can cause IAQ problems. Ventilation modifications can be used to isolate the work area and prevent pollutant build-up in occupied spaces. Proper storage practices can minimize the release of contaminants.

Problem #14:
Combustion Gases

Combustion odors can indicate the existence of a serious problem. One combustion product, carbon monoxide, is an odorless gas. Carbon monoxide poisoning can be life-threatening.

Air intakes are frequently located near the loading dock for aesthetic reasons. Unfortunately, this air intake placement can draw car and truck exhaust into the building, causing a variety of indoor air quality complaints.

Examples

Vehicle exhaust

- offices above (or connected to) an underground parking garage
- rooms near (or connected by pathways to) a loading dock or service garage

Combustion gases from equipment (e.g., spillage from inadequately vented appliances, cracked heat exchanger, re-entrainment because local chimney is too low)

- areas near a mechanical room
- distributed throughout zone or entire building

Solutions

Seal to remove pollutant pathway

- close openings between the contaminant source and the occupied space
- install well-sealed doors with automatic closers between the contaminant source and the occupied space

Remove source

- improve maintenance of combustion equipment
- modify venting or HVAC system to prevent backdrafting
- relocate holding area for vehicles at loading dock, parking area
- turn off engines of vehicles that are waiting to be unloaded

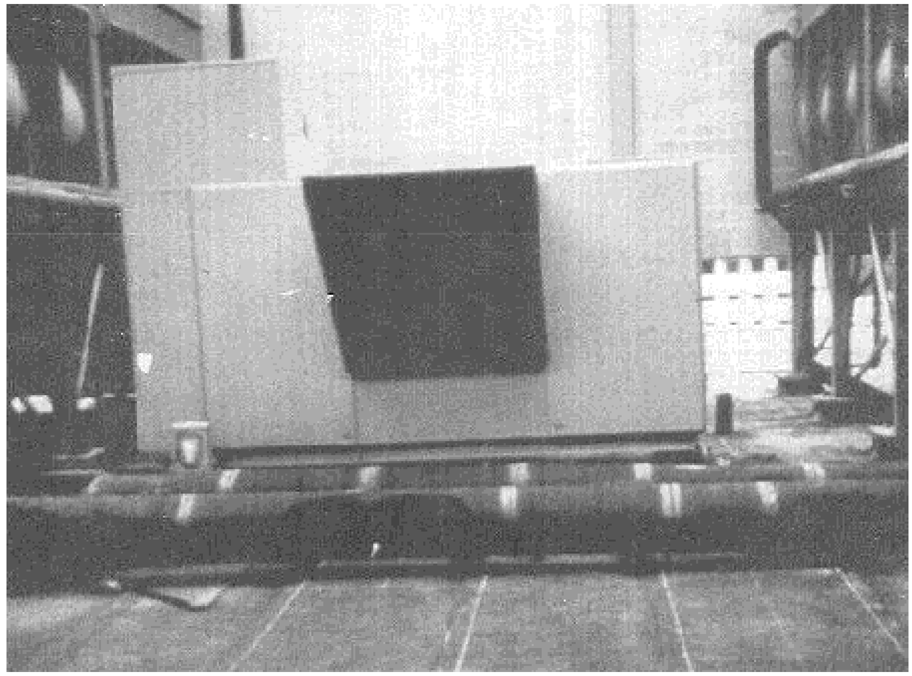
Modify ventilation system

- install local exhaust in underground parking garage (adjust HVAC system to provide make-up air and test to verify performance)
- relocate fresh air intake (move away from source of contaminants

Modify pressure relationships

- pressurize spaces around area containing source of combustion gases

Problem #15:
Serious Building-Related Illness



Some building-related illnesses can be life-threatening. Even a single confirmed diagnosis (which involves results from specific medical tests) should provoke an immediate and vigorous response.

Examples

Legionnaire's disease
(*Note:* If you suspect Legionnaire's disease, call the local public health department, check for obvious problem sites, and take corrective action. There is no way to be certain that a single case of this disease is associated with building occupancy; therefore, public health agencies usually do not investigate single cases. Watch for new cases.)

Hypersensitivity pneumonitis
(*Note:* Affected occupant(s) should be removed and may not be able to return unless the causative agent is removed from the affected person's environment.)

Solutions

Work with public health authorities

- evacuation may be recommended or required

Remove source

- drain, clean, and decontaminate drip pans, cooling towers, room unit air conditioners, humidifiers, dehumidifiers, and other habitats of *Legionella*, fungi, and other organisms using appropriate protective equipment
- install drip pans that drain properly
- provide access to all the items that must be cleaned, drained, or replaced periodically
- modify schedule and procedures for improved maintenance

Discontinue processes that deposit potentially contaminated moisture in air distribution system

- air washing
- humidification
- cease nighttime shutdown of air handlers

This air intake is located between the cooling towers. If the water in the cooling towers becomes contaminated with Legionella, *there is potential for Legionnaire's disease in the building.*

The most economical and successful solutions to IAQ problems are those in which the operating principle of the correction strategy makes sense and is suited to the problem.

JUDGING PROPOSED MITIGATION DESIGNS AND THEIR SUCESS

Mitigation efforts should be evaluated at the planning stage by considering the following criteria:

- permanence
- operating principle
- degree to which the strategy fits the job
- ability to institutionalize the solution
- durability
- installation and operating costs
- conformity with codes

Permanence

Mitigation efforts that create permanent solutions to indoor air problems are clearly superior to those that provide temporary solutions (unless the problems are also temporary). Opening windows or running air handlers on full outdoor air may be suitable mitigation strategies for a temporary problem such as outgassing of volatile compounds from new furnishings, but would not be good ways to deal with emissions from a print shop. A permanent solution to microbiological contamination involves not only cleaning and disinfection, but also modification of the environment to prevent regrowth.

Operating Principle

The most economical and successful solutions to IAQ problems are those in which the operating principle of the correction strategy makes sense and is suited to the problem. If a specific point source of contaminants has been identified, treatment at the source (e.g., by removal, sealing, or local exhaust) is almost always a more appropriate correction strategy than dilution of the contaminant by increased general ventilation. If the IAQ problem is caused by the introduction of outdoor air that contains contaminants, increased general ventilation will only make the situation worse (unless the outdoor air is cleaned).

Degree to Which the Strategy Fits the Job

It is important to make sure that you understand the IAQ problem well enough to select a correction strategy whose size and scope fit the job. If odors from a special use area such as a kitchen are causing complaints in a nearby office, increasing the ventilation rate in the office may not be a successful approach. The mitigation strategy should address the entire area affected.

If mechanical equipment is needed to correct the IAQ problem, it must be powerful enough to accomplish the task. For example, a local exhaust system should be strong enough and close enough to the source so that none of the contaminant is drawn into nearby returns and recirculated.

Ability to Institutionalize the Solution

A mitigation strategy will be most successful when it is institutionalized as part of normal building operations. Solutions that do not require exotic equipment are more likely to be successful in the long run than approaches that involve unfamiliar concepts or delicately maintained systems. If maintenance or housekeeping procedures or supplies must change as part of the mitigation, it may be necessary to plan for additional staff training, new inspection checklists, or modified purchasing practices. Operating schedules for HVAC equipment may also require modification.

Durability

IAQ mitigation strategies that are durable and low-maintenance are more attractive to owners and building staff than approaches that require frequent adjustment or specialized maintenance skills. New items of equipment should be quiet, energy-efficient, and durable, so that the operators are encouraged to keep them running.

Installation and Operating Costs

The approach with the lowest initial cost may not be the least expensive over the long run. Other economic considerations include: energy costs for equipment operation, increased staff time for maintenance; differential cost of alternative materials and supplies; and higher hourly rates if odor-producing activities (e.g., cleaning) must be scheduled for unoccupied periods. Although these costs will almost certainly be less than the cost of letting the problem continue, they are more readily identifiable, so an appropriate presentation to management may be required.

Conformity with Codes

Any modification to building components or mechanical systems should be designed and installed in keeping with applicable fire, electrical, and other building codes.

Judging the Success of a Mitigation Effort

Two kinds of criteria can be used to judge the success of an effort to correct an indoor air problem:

- reduced complaints
- measurement of properties of the indoor air (often only of limited usefulness)

Reduction or elimination of complaints appears to be a clear indication of success, but that is not necessarily the case. Occupants who see that their concerns are being heard may temporarily stop reporting discomfort or health symptoms, even if the actual cause of their complaints has not been addressed. Lingering complaints may also continue after successful mitigation if people have become upset over the

MANAGING MITIGATION PROJECTS INVOLVING SEVERE CONTAMINATION

Elements	Cautions
Identify the extent of contamination	Locating the original source of a chemical release or microbiological growth may only be the tip of the iceberg. Pollutants often tend to migrate through a building and collect in “sinks”, from which they can be resuspended into the air. For example, particles accumulate on horizontal surfaces that are not subject to regular housekeeping; odors may adsorb (stick) to porous materials. Detailed surface and/or bulk sampling may be needed to locate such “secondary” sources in order to solve an air quality problem.
Develop a precise scope of work specifying exactly how remediation will be performed	Depending on the problem, a detailed knowledge of chemistry, microbiology, building science, and health and safety may be required.
Monitor remediation to ensure work practices are followed	Include air sampling along with regular inspections if needed. Decontamination of areas within an occupied building is especially critical.
Conduct clearance sampling	In the event of severe contamination, representative air samples should be collected to ensure that key indicators have returned to background levels and that the space can be safely reoccupied.

Many routine IAQ problems can be corrected by a common sense approach not requiring special expertise. However, when complex exposure or contamination issues are involved, more detailed technical assistance may be needed for successful remediation. Efforts such as those outlined above are sometimes needed to deal with severe contamination.

If you have made several unsuccessful efforts to control a problem, then it may be advisable to seek outside assistance.

handling of the problem. Ongoing (but reduced) complaints could also indicate that there were multiple IAQ problems and that one or more problems are still unresolved.

However, it can be very difficult to use measurements of contaminant levels as a means of determining whether air quality has improved. Concentrations of indoor air pollutants typically vary greatly over time; further, the specific contaminant measured may not be causing the problem. If air samples are taken, readings taken before and after mitigation should be interpreted cautiously. It is important to keep the "before" and "after" conditions as identical as possible, except for the operation of the control strategy. For example, the same HVAC operation, building occupancy and climatic conditions should apply during both measurement periods. "Worst-case" conditions identified during the investigation should be used.

Measurements of airflows, ventilation rates, and air distribution patterns are the more reliable methods of assessing the results of control efforts. Airflow measurements taken during the building investigation can identify areas with poor ventilation; later they can be used to evaluate attempts to improve the ventilation rate, distribution, or direction of flow. Studying air distribution patterns will show whether a mitigation strategy has successfully prevented a contaminant from being transported by airflow.

Persistent Problems

Solving an indoor air quality problem is a cyclical process of data collection and hypothesis testing. Deeper and more detailed investigation is needed to suggest new hypotheses after any unsuccessful or partially-successful control attempt.

Even the best-planned investigations and mitigation actions may not produce a resolution to the problem. You may have made a careful investigation, found one or more apparent causes for the problem, and implemented a control system. Nonetheless, your correction strategy may not have caused a noticeable reduction in the concentration of the contaminant or improvement in ventilation rates or efficiency. Worse, the complaints may persist even though you have been successful at improving ventilation and controlling all of the contaminants you could identify. When you have pursued source control options and have increased ventilation rates and efficiency to the limits of your expertise, you must decide how important it is to pursue the problem further.

If you have made several unsuccessful efforts to control a problem, then it may be advisable to seek outside assistance. The problem is probably fairly complex, and it may occur only intermittently or cross the borders that divide traditional fields of knowledge. It is even possible that poor indoor air quality is not the actual cause of the complaints. Bringing in a new perspective at this point can be very effective.

The next section provides guidance on hiring professional indoor air quality assistance. An interdisciplinary team (such as people with engineering and medical or health backgrounds) may be needed to solve particularly difficult problems.

Hiring Professional Assistance to Solve an IAQ Problem

8

Many IAQ problems are simple to resolve when facility staff have been educated about the investigation process. In other cases, however, a time comes when outside assistance is needed. Professional help might be necessary or desirable in the following situations, among others:

- Mistakes or delays could have serious consequences (e.g., health hazards, liability exposure, regulatory sanctions).
- Building management feels that an independent investigation would be better received or more effectively documented than an in-house investigation.
- Investigation and mitigation efforts by facility staff have not relieved the IAQ problem.
- Preliminary findings by staff suggest the need for measurements that require specialized equipment and training beyond in-house capabilities.

You may be able to find help by looking in the yellow pages of your telephone book (e.g., under "Engineers," "Environmental Services," "Laboratories - Testing," or "Industrial Hygienists"). Local or State health or air pollution agencies may have lists of firm offering IAQ services in your area. It may also be useful to seek out referrals from other building management firms.

Local, State, or Federal government agencies may be able to provide expert assistance or direction in solving IAQ problems. It is particularly important to contact your local or State Health Department if you suspect that you have a serious building-related illness potentially linked to biological contamination in your building.

If available government agencies do not have personnel with the appropriate skills to assist in solving your IAQ problem, they may be able to direct you to firms in your area with experience in indoor air quality work. Note that even certified professionals from disciplines closely related to IAQ issues (such as industrial hygienists, ventilation engineers, and toxicologists) may not have the specific expertise needed to investigate and resolve indoor air problems. Individuals or groups that offer services in this evolving field should be questioned closely about their related experience and their proposed approach to your problem.

As with any hiring process, the better you know your own needs, the easier it will be to select a firm or individual to service those needs. Firms and individuals working in IAQ may come from a variety of disciplines. Typically, the skills of HVAC engineers and industrial hygienists are useful for this type of investigation, although input from other disciplines such as chemistry, chemical engineering, architecture, microbiology, or medicine may also be important. If problems other than indoor air quality are involved, experts in lighting, acoustic design, interior design, psychology, or other fields may be helpful in resolving occupant complaints about the indoor environment.

MAKE SURE THAT *THEIR* APPROACH FITS *YOUR* NEEDS

As you prepare to hire professional services in the area of indoor air quality, be aware it is a developing area of knowledge. Most consultants working in the field received their primary training in other areas. A variety of investigative methods may be employed, many of which are ineffective for resolving any but the most obvious

As you prepare to hire professional services in the area of indoor air quality, be aware that it is a developing area of knowledge.

Diagnostic outcomes to avoid include an evaluation that overemphasizes measuring concentrations of pollutants and a report that links all the deficiencies in the building to the problem without considering their actual association with the complaints.

situations. Inappropriately designed studies may lead to conclusions that are either false negative (e.g., falsely concludes that there is no problem associated with the building) or false positive (e.g., incorrectly attributes the cause to building conditions).

Diagnostic outcomes to avoid include:

- an evaluation that overemphasizes measuring concentrations of pollutants and comparing those concentrations to numerical standards, and
- a report that lists a series of major and minor building deficiencies and links all the deficiencies to the problem without considering their actual association with the complaints.

Considerable care should be exercised when interviewing potential consultants to avoid those subscribing to these strategies. A qualified IAQ investigator should have appropriate experience, demonstrate a broad understanding of indoor air quality problems and the conditions which can lead to them, and use a phased diagnostic approach.

SELECTION CRITERIA

Most of the criteria used in selecting a professional to provide indoor air quality services are similar to those used for other professionals:

- company experience in solving similar problems, including training and experience of the individuals who would be responsible for the work
- quality of interview and proposal
- company reputation
- knowledge of local codes and regional climate conditions
- cost

Experience

An EPA survey of firms providing IAQ services found that almost half had been providing IAQ diagnostic or mitigation services in non-industrial settings for ten or fewer years.

- Ask how much IAQ work and what type of IAQ work the firm has done.
- Have the firm identify the personnel who would be responsible for your case, their specific experience, and related qualifications. Contract only for the services of those individuals, or require approval for substitutions.

Quality of Interview and Proposal

Several guidelines may be of assistance in hiring IAQ professionals.

1. Competent professionals will ask questions about your situation to see whether they feel they can offer services that will assist you.

The causes and potential remedies for indoor air quality problems vary greatly. A firm needs at least a preliminary understanding of the facts about what is going on in your building to evaluate if it has access to the professional skills necessary to address your concerns and to make effective use of its personnel from the outset. Often a multi-disciplinary team of professionals is needed.

2. The proposal for the investigation should emphasize observations rather than measurements.

Section 6 describes the four types of information that may need to be gathered in an investigation in order to resolve an indoor air quality problem: the occupant complaints, the HVAC system, pollutant pathways, and pollutant sources. There is also a discussion of the role of monitoring within an investigation. Non-routine measurements (such as relatively expensive sampling for VOCs) should not be provided without site-specific justification.

3. The staff responsible for building investigation should have a good understanding of the relationship between IAQ and the building structure, mechanical systems, and human activities.

For example, lack of adequate ventilation is at least a contributing factor in many indoor air quality problem situations. Evaluating the performance of the ventilation system depends on understanding the interaction between the mechanical system and the human activity within the building.

In some cases building investigators may have accumulated a breadth of knowledge. For example, a mechanical engineer and an industrial hygienist see buildings differently. However, a mechanical engineer with several years of experience in IAQ problem investigations may have seen enough health-related problems to cross the gap; likewise, an industrial hygienist with years of experience studying problems in an office setting may have considerable expertise in HVAC and other building mechanical systems.

Either in the proposal or in discussion, the consultant should:

- Describe the goal(s), methodology, and sequence of the investigation, the information to be obtained, and the process of hypothesis development and testing, including criteria for decision-making about further data-gathering. The proposal should include an explanation of the need for any proposed measurements. The goal is to reach a successful resolution of the complaints, not simply to generate data.
- Identify any elements of the work that will require a time commitment from the client's own staff, including information to be collected by the client.
- Identify additional tasks (and costs) which are part of solving the IAQ problem but are outside the scope of the contract. Examples might include medical examination of complainants, laboratory fees, and contractor's fees for mitigation work.
- Describe the schedule, cost, and work product(s), such as a written report, specifications, and plans for mitigation work; supervision of mitigation work; and training program for building staff.
- Discuss communication between the IAQ professional and the client: How often will the contractor discuss the progress of the work with the client? Who will be notified of test results and other data? Will communications be in writing, by telephone, or face-to-face? Will the consultant meet with building occupants to collect information? Will the consultant meet with occupants to discuss findings if requested to do so?

Reputation

There are no Federal regulations covering professional services in the general field of indoor air quality, although some disciplines (e.g., engineers, industrial hygienists) whose practitioners work with IAQ problems have licensing and certification requirements.

Building owners and managers who suspect that they may have a problem with a specific pollutant (such as radon, asbestos, or lead) may be able to obtain assistance from local and State Health Departments. Government agencies and affected industries have developed training programs for contractors who diagnose or mitigate problems with these particular contaminants.

Firms should be asked to provide references from clients who have received comparable services. In exploring refer-

The goal of the investigative process is to reach a successful resolution of the complaints, not simply to generate data.

ences, it is useful to ask about long-term follow-up. After the contract was completed, did the contractor remain in contact with the client to ensure that problems did not recur?

Knowledge of Local Codes and Regional Climate Conditions

Familiarity with State and local regulations and codes helps to avoid problems during mitigation. For example, in making changes to the HVAC system, it is important to conform to local building codes. Heating, cooling, and humidity control needs are different in different geographic regions, and can affect the selection of an appropriate mitigation approach. Getting assurances that all firms under consideration have this knowledge becomes particularly important if it becomes necessary to seek expertise from outside the local area.

Cost

It is impossible for this document to give specific guidance on the cost of professional services. If projected costs jump suddenly during the investigation process, the consultants should be able to justify that added cost.

The budget will be influenced by a number of factors, including:

- complexity of the problem
- size and complexity of the building and its HVAC system(s)
- quality and extent of recordkeeping by building staff and management
- type of report or other product required
- number of meetings required (formal presentations can be quite expensive)
- air sampling (e.g., use of instruments, laboratory analysis) if required

APPENDICIES

Building Air Quality

Printed on Recycled Paper

Appendix A: Common IAQ Measurements - A General Guide

The following is a brief introduction to making measurements that might be needed in the course of developing an IAQ profile or investigating an IAQ complaint. Emphasis has been placed on the parameters most commonly of interest in non-research studies, highlighting the more practical methods and noting some inappropriate tests to avoid. Most of the instruments discussed in this section are relatively inexpensive and readily available from many local safety supply companies. Consult the guidance in *Section 6* on pages 72-73 before determining whether to proceed with air sampling.

OVERVIEW OF SAMPLING DEVICES

Air contaminants of concern in IAQ can be measured by one or more of the following methods:

Vacuum Pump:
A vacuum pump with a known airflow rate draws air through collection devices, such as a *filter* (catches airborne particles), a *sorbent tube* (which attracts certain chemical vapors to a powder such as carbon), or an *impinger* (bubbles the contaminants through solution in a test tube). Tests originated for industrial environments typically need to be adjusted to a lower detection limit for IAQ work. Labs can be asked to report when trace levels of an identifiable contaminant are present below the limit of quantification and detection.

In adapting an industrial hygiene sorbent tube sampling method for IAQ, the investigator must consider at least two important questions. First: are the emissions to be measured from a product's end use the same as those of concern during manufacturing? Second: is it necessary to increase the air volume sampled? Such an increase may be needed to detect the presence of contaminants at the low concentrations usually found in non-industrial settings. For example, an investigator might have to increase sampling time from 30 minutes to 5 hours in order to detect a substance at the low concentrations found during IAQ investigations. In cases where standard sampling methods are changed, qualified industrial hygienists and chemists should be consulted to ensure that accuracy and precision remain acceptable.

Direct-reading Meter:
Direct-reading meters estimate air concentrations through one of several detection principles. These may report specific

SELECTING MEASUREMENT DEVICES

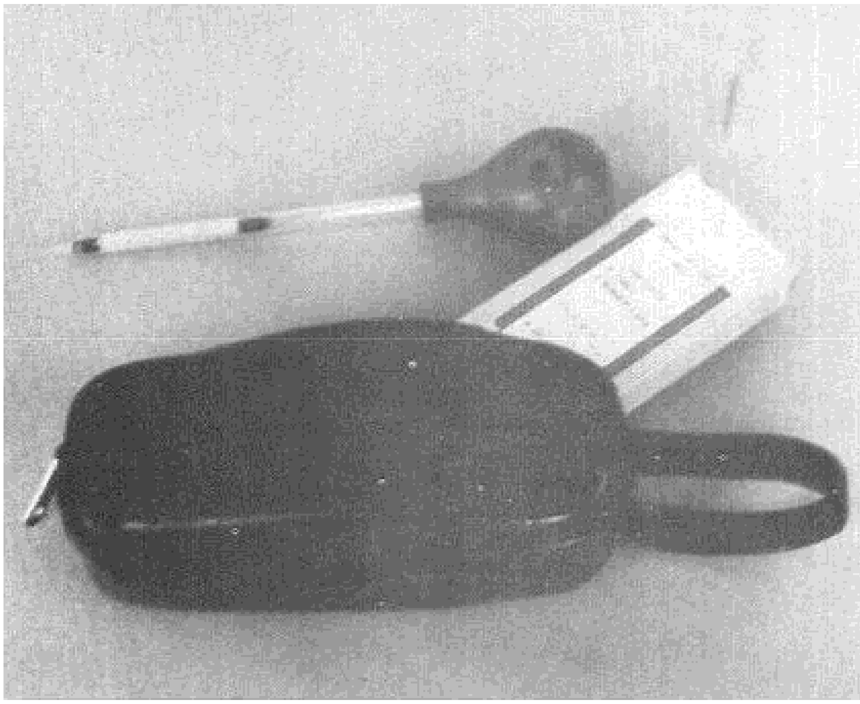
The growing interest in indoor air quality is stimulating the development of instruments for IAQ research and building investigations. As you evaluate the available measurement devices, it may be helpful to consider the following criteria:

Ease of use
- portability
- direct-reading vs. analysis required
- ruggedness
- time required for each measurement

Quality assurance
- availability of service and customer support
- maintenance and calibration requirements

Output
- time-averaged vs. instantaneous readings
- sensitivity
- compatibility with computer or data logging accessories

Cost
- single use only vs. reusable
- purchase vs. rental



Above: A smoke tube, which is one type of chemical smoke device. Used to observe patterns of air movement and the direction (negative or positive) of pressure differences. Below: A microman-ometer. Used for measuring pressure differentials to learn about airflow. Provides quantitative data, as compared to the qualitative information provided by chemical smoke.

chemicals (e.g., CO_2 by infrared light), chemical groups (e.g., certain volatile organics by photoionization potential) or broad pollutant categories (e.g., all respirable particles by scattered light). Detection limits and averaging time developed for industrial use may or may not be appropriate for IAQ.

Detector tube kit:
Detector tube kits generally include a hand pump that draws a known volume of air through a chemically treated tube intended to react with certain contaminants. The length of color stain resulting in the tube correlates to chemical concentration.

Personal monitoring devices:
Personal monitoring devices (sometimes referred to as “dosimeters”) are carried or worn by individuals and are used to measure that individual’s exposure to particular chemical(s). Devices that include a pump are called “active” monitors; devices that do not include a pump are called “passive” monitors. Such devices are currently used for research purposes. It is possible that sometime in the future they may also be helpful in IAQ investigations in public and commercial buildings.

SIMPLE VENTILATION/COMFORT INDICATIONS

Thermal Comfort: Temperature and Relative Humidity

The sense of thermal comfort (or discomfort) results from an interaction between temperature, relative humidity, air movement, clothing, activity level, and individual physiology. Temperature and relative humidity measurements are indicators of thermal comfort.

Methodology

Measurements can be made with a simple thermometer and sling psychrometer or with electronic sensors (e.g., a thermo-hygrometer). Accuracy of within + or - 1°F is recommended for temperature measurements. For each measurement, time should be allowed for the reading to stabilize to room conditions. Refer to the specifications for the measuring device; some take several minutes to stabilize. Electronic relative humidity (RH) meters must be calibrated frequently.

Indoor relative humidity is influenced by outdoor conditions. A single indoor measurement may not be a good indication of long-term relative humidity in the building. Programmable recording sensors can be used to gain an understanding of temperature or humidity conditions as they change over time.

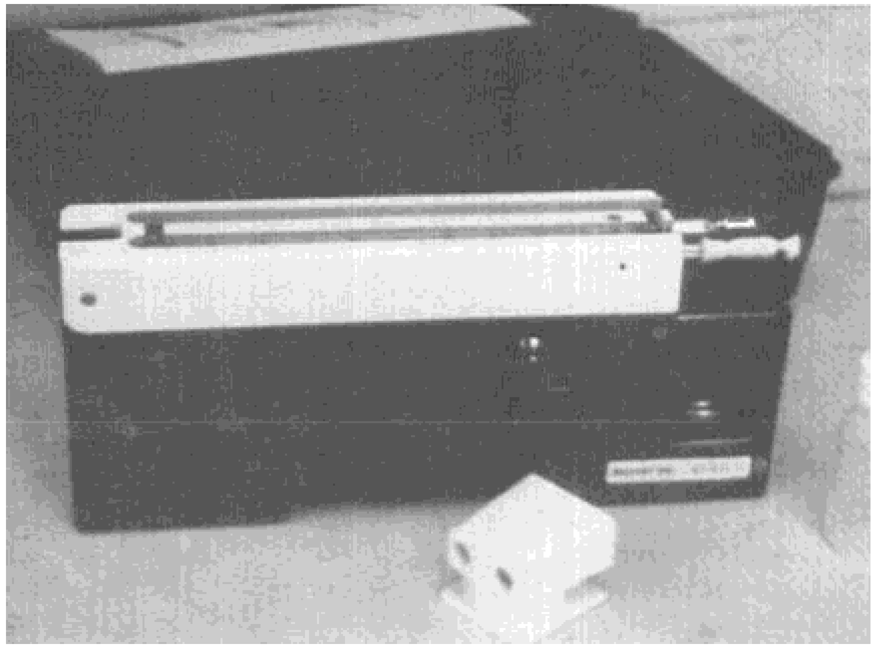
Using the Results

Temperature and humidity directly affect thermal comfort. They may also provide indirect indications of HVAC condition and the potential for airborne contamination from biological or organic compounds. There is considerable debate among researchers, IAQ professionals, and health professionals concerning recommended levels of relative humidity; however, the humidity levels recommended by different organizations generally range between 30% and 60% RH.

Comparison of indoor and outdoor temperature and humidity readings taken during complaint periods can indicate whether thermal discomfort might be due to extreme conditions beyond the design capacity of HVAC equipment or the building envelope.

Measure next to thermostats to confirm calibration. Measure at the location of complaints to evaluate whether or not temperature and humidity at that location are within the comfort zone (see Figure 6-2 on page 57).

Readings that show large variations within the space may indicate a room air distribution or mixing problem. Readings that are highly variable over time may indicate control or balance problems with the HVAC systems.



A psychrometer. Used to measure dry bulb and wet bulb temperatures and to determine relative humidity based upon a psychometric chart. The NIOSH protocol for indoor air investigations always includes measurement of indoor and outdoor relative humidity. There are two types of psychrometers: aspirated (with a fan) or sling (without a fan).

Tracking Air Movement with Chemical Smoke

Chemical smoke can be helpful in evaluating HVAC systems, tracking potential contaminant movement, and identifying pressure differentials. Chemical smoke moves from areas of higher pressure to areas of lower pressure if there is an opening between them (e.g., door, utility penetration). Because it is heatless, chemical smoke is extremely sensitive to air currents. Investigators can learn about airflow patterns by observing the direction and speed of smoke movement. Puffs of smoke released at the shell of the building (by doors, windows, or gaps) will indicate whether the HVAC systems are maintaining interior spaces under positive pressure relative to the outdoors.

Methodology

Chemical smoke is available with various dispensing mechanisms, including smoke "bottles," "guns," "pencils," or "tubes." The dispensers allow smoke to be released in controlled quantities and directed at specific locations. It is often more informative to use a number of small puffs of smoke as you move along an air pathway rather than releasing a large amount in a single puff. (*Note:* Avoid direct inhalation of chemical smoke, because it can be irritating. Do not release smoke directly on smoke detectors.)

Using the Results

Smoke released mid-room: Observation of a few puffs of smoke released in mid-room or mid-cubicle can help to visualize air circulation within the space. Dispersal of smoke in several seconds suggests good air circulation, while smoke that stays essentially still for several seconds suggests poor circulation. Poor air circulation may contribute to sick building syndrome complaints or may contribute to comfort complaints even if there is sufficient overall air exchange.

Smoke released near diffusers, grilles: Puffs of smoke released by HVAC vents give a general idea of airflow. (Is it in or out? Vigorous? Sluggish? No flow?) This is helpful in evaluating the supply and return system and determining whether ventilation air actually reaches the breathing zone. (For a variable air volume system, be sure to take into account how the system is designed to modulate. It could be on during the test, but off for much of the rest of the day.) "Short-circuiting" occurs when air moves relatively directly from supply diffusers to return grilles, instead of mixing with room air in the breathing zone. When a substantial amount of air short-circuits, occupants may not receive adequate supplies of outdoor air and source emissions may not be diluted sufficiently.

Carbon Dioxide (CO_2) as an Indicator of Ventilation

CO_2 is a normal constituent of the atmosphere. Exhaled breath from building occupants is an important indoor CO_2 source. Indoor CO_2 concentrations can, under some test conditions, provide a good indication of the adequacy of ventilation. Comparison of peak CO_2 readings between rooms, between air handler zones, and at varying heights above the floor, may help to identify and diagnose various building ventilation deficiencies.

Methodology

CO_2 can be measured with either a direct-reading meter or a detector tube kit. The relative occupancy, air damper settings, and weather should be noted for each period of CO_2 testing.

CO_2 measurements for ventilation should be collected away from any source that could directly influence the reading (e.g., hold the sampling device away from exhaled breath). Individual measurements should be short-term. As with many other measurements of indoor air conditions, it is advisable to take one or more readings in "control" locations to serve as baselines for comparison. Readings from outdoors and from areas in which there are no apparent IAQ problems are frequently used as controls. Outdoor samples should be taken near the outdoor air intake.

Measurements taken to evaluate the adequacy of ventilation should be made when concentrations are expected to peak. It may be helpful to compare measurements taken at different times of day. If the occupant population is fairly stable during normal business hours, CO_2 levels will typically rise during the morning, fall during the lunch period, then rise again, reaching a peak in mid-afternoon. In this case, sampling in the mid- to late-afternoon is recommended. Other sampling times may be necessary for different occupancy schedules.

Using the Results

Peak CO_2 concentrations above 1000 ppm in the breathing zone indicate ventilation problems. Carbon dioxide concentrations below 1000 ppm generally indicate that ventilation is adequate to deal with the routine products of human occupancy.

However, there are several reasons not to conclude too quickly that a low CO_2 reading means no IAQ problem exists. Problems can occur in buildings in which measured CO_2 concentrations are below 1000 ppm. Although CO_2 readings indicate good ventilation, for example, if strong contaminant sources are present, some sort of source control may be needed to prevent IAQ problems. Errors in measurement and varying CO_2 concentrations over time can also cause low readings that may be misleading.

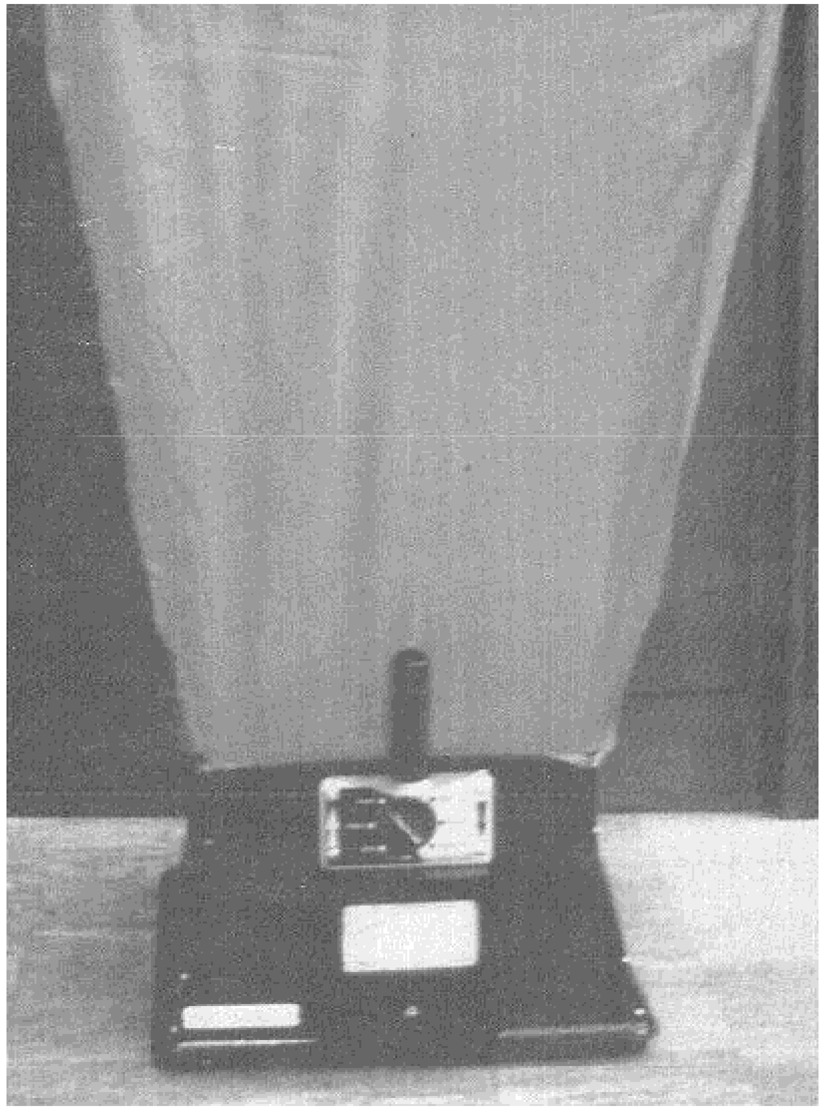
Elevated CO_2 may be due to various causes alone or in combination, such as: increased occupant population, air exchange rates below ASHRAE guidelines, poor air distribution, and poor air mixing. A higher average CO_2 concentration in the general breathing zone (at least two feet from exhaled breath) than in the air entering return grilles is an indication of poor air mixing. Smoke tubes and temperature profiles will help to clarify air circulation patterns.

If CO_2 measurements taken before the occupied period begins are higher than outdoor readings taken at the same time, there may be an operating problem with the HVAC system. Potential problems include the following:

- ventilation terminated too early the evening before (as compared with the occupancy load on the space)
- combustion by-products from a nearby roadway or parking garage are drawn into the building
- a gas-fired heating appliance in the building has a cracked heat exchanger

Outdoor CO_2 concentrations above 400 ppm may indicate an outdoor contamination problem from traffic or other combustion sources. Note, however, that detector tubes cannot provide accurate measurements of CO_2 in hot or cold weather.

Measuring Airflow

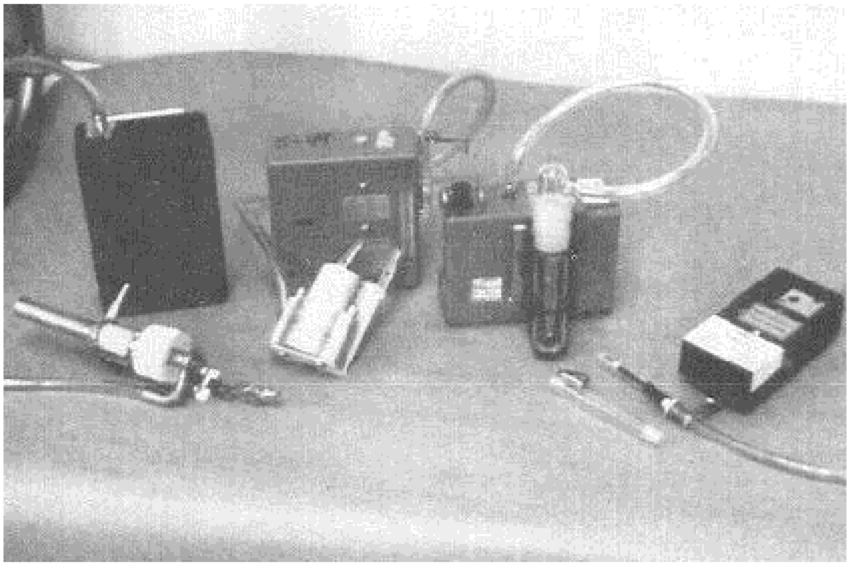


A flow hood. Used to measure the total air flow (outdoor plus recirculated air) from a diffuser.

Measurements of airflow allow investigators to estimate the amount of outdoor air that is entering the building and to evaluate HVAC system operation. The most appropriate measurement technique depends on the characteristics of the measurement location.

Methodology

Airflow quantities can be calculated by measuring the velocity and cross-sectional area of the airstream. For example, if air is moving at 100 feet per minute in a 24” x



A vacuum pump with attachments for sampling with a filter, a sorbent tube, and an impinger. Use in a non-industrial setting may require a larger volume of air. Consult with qualified industrial hygienists and chemists if adapting sampling methods.

12" duct, the airflow is:

100 feet/minute x 2 square feet duct area = 200 cubic feet/minute

Air velocity can be measured with a pitot tube or anemometer. Air velocity within an airstream is likely to vary considerably. For example, it is extremely difficult to measure air velocity at supply diffusers because of turbulence around the mixing vanes. The best estimates of air velocity can be achieved by averaging the results of a number of measurements. ASTM Standard Practice D 3154 provides guidance on making such measurements. This method is available from ASTM. (See *Appendix G* for ASTM's address and phone number.) The cross-sectional area of the airstream is sometimes easy to calculate (e.g., in a straight run of rectangular ductwork), but can be very complicated at other locations such as mixing boxes or diffusers.

Flow hoods can be used for direct measurement of airflows at locations such as grilles, diffusers, and exhaust outlets. They are not designed for use in ductwork.

Using the Results

Airflow measurements can be used to determine whether the HVAC system is operating according to design and to identify potential problem locations. Building investigations often include measurements of outdoor air quantities, exhaust air quantities, and airflows at supply diffusers and return grilles.

Estimating Outdoor Air Quantities

Outdoor air quantities can be evaluated by measuring airflow directly. Investigators often estimate the proportion of outdoor air quantities using techniques such as thermal mass balance (temperature) or CO_2 measurements. Estimation of outdoor air quantity using temperature measurements is referred to as "thermal balance" or sometimes "thermal mass balance."

Thermal Balance: Methodology

Use of this test requires the following conditions:

1. Airstreams representing return air, outdoor air, and mixed air (supply air before it has been heated or cooled) are accessible for separate measurement. Some systems are already equipped with an averaging thermometer that is strung diagonally across the mixed air chamber; the temperature is read out continuously on an instrument panel. Some panels read out supply, return, outdoor, and/or mixed air temperature.

2. There is at least a several degree temperature difference between the building interior and the outdoor air.

3. Total air flow in the air handling system can be estimated either by using recent balancing reports or pitot tube measurements in ductwork. As an alternative, the supply air at each diffuser can be estimated (e.g., using a flow measuring hood), and the results can be summed to calculate total system air flow.

Temperature measurements can be made with a simple thermometer or an electronic sensor. Several measurements should be taken across each airstream and averaged.

It is generally easy to obtain a good temperature reading in the outdoor air and return airstreams. To obtain a good average temperature reading of the mixed airstream, a large number of measurements must be taken upstream of the point at which the airstream is heated or cooled. This may be difficult or impossible in some systems.

The percentage or quantity of outdoor air is calculated using thermal measurements as shown to the right.

Methodology: Carbon Dioxide Measurements

CO_2 readings can be taken at supply outlets or air handlers to estimate the percentage of outdoor air in the supply airstream. The percentage or quantity of outdoor air is calculated using CO_2 measurements as shown to the right.

Using the Results

The results of this calculation can be compared to the building design specifications, applicable building codes, or ventilation recommendations such as ASHRAE 62-1989 (see page 136 in *Appendix B*) to see whether underventilation appears to be a problem.

ESTIMATING OUTDOOR AIR QUANTITIES

Using Thermal Mass Balance

Outdoor air (percent) = $$\frac{T_{\text{return air}} - T_{\text{mixed air}}}{T_{\text{return air}} - T_{\text{outdoor air}}} \times 100$$

Where: T = temperature (degrees Farenheit)

Using Carbon Dioxide Measurements

Outdoor air (%) = $$\frac{C_S - C_R}{C_O - C_R} \times 100$$

Where: C_S = ppm CO_2 in the supply air (if measured in a room), or
C_S = ppm of CO_2 in the mixed air (if measured at an air handler)
C_R = ppm of CO_2 in the return air
C_O = ppm of CO_2 in the outdoor air

(All these concentrations must be measured, not assumed.)

Converting Percent To CFM

Outdoor air (in cfm) = $$\frac{\text{Outdoor air (percent)}}{100} \times \text{total airflow (cfm)}$$

Where: cfm = cubic feet per minute

The number used for total airflow may be the air quantity supplied to a room or zone, the capacity of an air handler, or the total airflow of the HVAC system. Note: The actual amount of airflow in an air handler is often different from the quantity in design documents.

AIR CONTAMINANT CONCENTRATIONS

Volatile Organic Compounds (VOCs)

Hundreds of organic (carbon-containing) chemicals are found in indoor air at trace levels. VOCs may present an IAQ problem when individual organics or mixtures exceed normal background concentrations.

Methodology: Total Volatile Organic Compounds (TVOCs)

Several direct-reading instruments are available that provide a **low sensitivity** "total" reading for different types of organics. Such estimates are usually presented in parts per million and are calculated with the assumption that all chemicals detected are the same as the one used to calibrate the instrument. A photoionization detector is an example of a direct-reading instrument used as a screening tool for measuring TVOCs.

A laboratory analysis of a sorbent tube can provide an estimate of total solvents in the air. Although methods in this category report "total volatile organic compounds" (TVOCs) or "total hydrocarbons" (THC), analytical techniques differ in their sensitivity to the different types of organics. (For discussion of measurement devices and their sensitivity, see *Overview of Sampling Devices* on page 109.)

Using the Results

Different measurement methods are useful for different purposes, but their results should generally not be compared to each other. Direct-reading instruments do not provide sufficient sensitivity to differentiate normal from problematic mixtures of organics. However, instantaneous readouts may help to identify "hot spots," sources, and pathways. TVOCs or THC determined from sorbent tubes provide more accurate average readings, but are unable to distinguish peak exposures. A direct-reading instrument can identify peak exposures if they happen to occur during the measurement period.

Methodology: Individual Volatile Organic Compounds (VOCs)

High concentrations of individual volatile organic compounds (VOCs) may also cause IAQ problems. Individual VOCs can be measured in indoor air with a moderate degree of sensitivity (i.e., measurement in parts per million) through adaptations of existing industrial air monitoring technology. Examples of **medium sensitivity** testing devices include XAD-4 sorbent tubes (for nicotine), charcoal tubes (for solvents), and chromosorb tubes (for pesticides). After a sufficient volume of air is pumped through these tubes, they are sent to a lab for extraction and analysis by gas chromatography. Variations use a passive dosimeter (charcoal badge) to collect the sample or a portable gas chromatograph onsite for direct injection of building air. These methods may not be sensitive enough to detect many trace level organics present in building air.

High sensitivity techniques have recently become available to measure "trace organics" — VOCs in the air (i.e. measurements in parts per billion.) Sampling may involve Tenax and multiple sorbent tubes, charcoal tubes, evacuated canisters, and other technology. Analysis involves gas chromatography followed by mass spectroscopy.

Using the Results

Guidelines for public health exposure (as opposed to occupational exposure) for a few VOCs are available in the World Health Organization (WHO) Air Quality Guidelines for Europe. These guidelines address noncarcinogenic and carcinogenic effects. Occupational exposure standards exist for many other VOCs. No rule-of-thumb safety factor for applying these occupational limits to general IAQ is currently endorsed by EPA and NIOSH.

Measurement of trace organics may identify the presence of dozens to hundreds of trace VOCs whose significance is difficult to determine. It may be helpful to compare levels in complaint areas to levels in outdoor air or non-complaint areas.

Formaldehyde

Formaldehyde is a VOC that has been studied extensively. Small amounts of formaldehyde are present in most indoor environments. Itching of the eyes, nose, or throat may indicate an elevated concentration. Sampling may be helpful when relatively new suspect materials are present.

Methodology

A number of measurement methods are available. Sensitivity and sampling time are very important issues in selecting a method; however, many methods allow detection of concentrations well below 0.1 ppm (see *Using the Results* below). Measurement of short-term peaks (around a two-hour sample time) is ideal for evaluating acute irritation. Dosimeters may accurately record long-term exposure but may miss these peaks.

Two commonly used methods that are generally acceptable for IAQ screening involve impingers and sorbent tubes. Other appropriate methods are also available.

Using the Results

Various guidelines and standards are available for formaldehyde exposure. Several organizations have adopted 0.1 ppm as guidance that provides reasonable protection against irritational effects in the normal population. Hypersensitivity reactions may occur at lower levels of exposure. Worst-case conditions are created by minimum ventilation, maximum temperatures, and high source loadings.

Biological Contaminants

Human health can be affected by exposure to both living and non-living biological contaminants. The term "bioaerosols" describes airborne material that is or was living, such as mold and bacteria, parts of living organisms (e.g., insect body parts), and animal feces.

Testing for biological contaminants should generally be limited to:

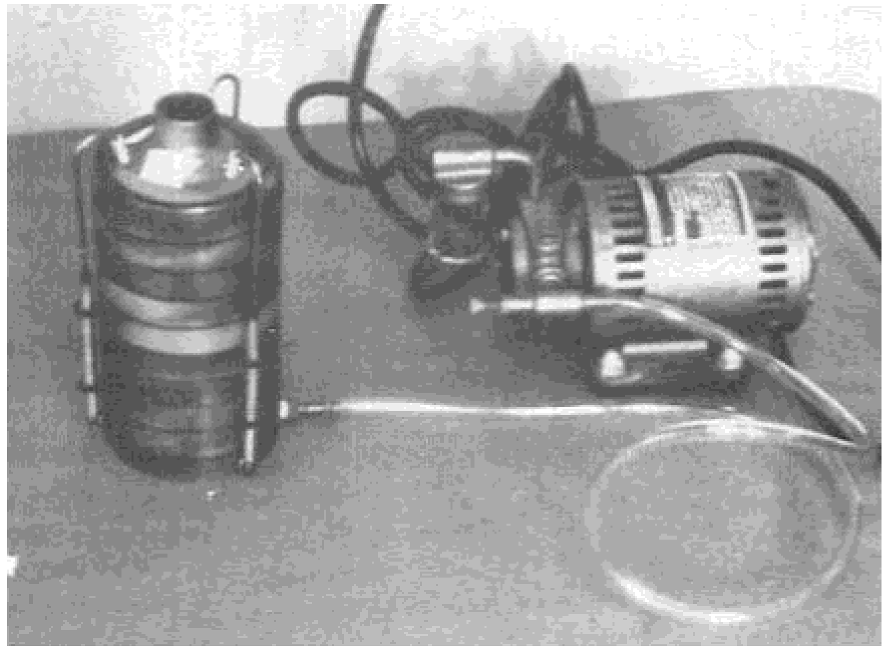
- cases where a walkthrough investigation or human profile study suggests microbiological involvement
- cases in which no other pollutant or physical condition can account for symptoms

Methodology

Inspection of building sanitary conditions is generally preferred over sampling, because direct sampling can produce misleading results. Any sampling should be accompanied by observations of sanitary conditions and a determination as to whether any health problems appear likely to be related to biological contamination.

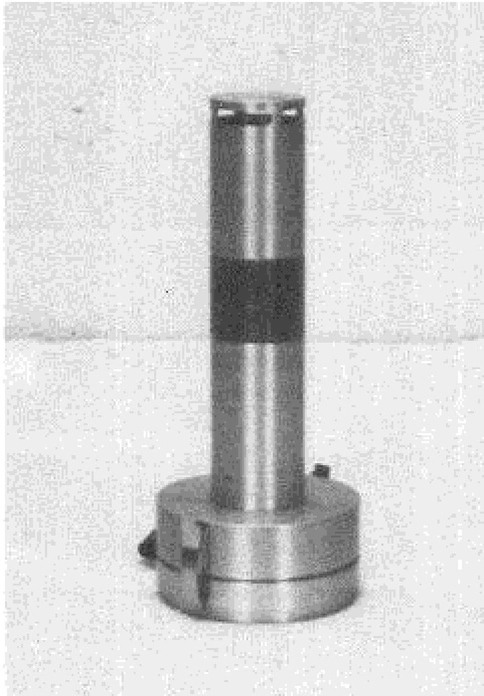
No single technique is effective for sampling the many biological contaminants found in indoor environments. A variety of specific approaches are used to retrieve, enumerate, and identify each kind of microorganism from water, surfaces, and air. Other specific methods are used for materials such as feces or insect parts. The utility of these techniques depends upon their use by professionals who have a thorough understanding of the sample site and the target organism.

Where air sampling is desired, several approaches are available. The most common type of air sampler uses a pump to pull air across a nutrient agar, which is then incubated. Any bacterial or fungal colonies that subsequently grow can be counted and identified by a qualified microbiologist. Different types of agar and incubation temperatures are used to culture different types of organisms. Only living organisms or spores in the air are counted by this method. Settling plates, which are simply opened to room air and then incubated, are sometimes used to identify which bioaerosols are present in different locations. The drawbacks to this technique are that it does not indicate the quantity of bioaerosols present and that only the



A viable impactor. Used to sample for biologicals. Training is required in order to analyze the results.

High-flow indoor particulate sampler. Used to measure particles 10 microns and smaller that are readily inhaled.



bioaerosols that are heavy enough to fall out onto the agar will be recorded.

Using the Results

Quantities and types of bioaerosols can vary greatly over time in any given building, making sampling results difficult to interpret. Comparison of relative numbers and types between indoors and outdoors or between complaint areas and background sites can help to establish trends; however, no tolerance levels or absolute guidelines have been established. Low bioaerosol results by themselves are not considered proof that a problem does not exist, for a variety of reasons:

- the sampling and identification techniques used may not be suited to the type(s) of bioaerosols that are present
- biological growth may have been inactive during the sampling period
- the analysis technique used may not reveal non-living bioaerosols (e.g., feces, animal parts) that can cause health reactions

Airborne Dust

Particles and fibers suspended in the air generally represent a harmless background but can become a nuisance or cause serious health problems under some conditions.

Methodology

A variety of collection and analytical techniques are available. Dust can be collected by using a pump to draw air through a filter. The filter can then be weighed (gravimetric analysis) or examined under a microscope. Direct readouts of airborne dust are also available (such as using meters such as those equipped with a "scattered light" detector).

Using the Results

IAQ measurements for airborne dust will be well below occupational and ambient air guidelines except under the most extreme conditions. Unusual types or elevated amounts of particles or fibers can help identify potential exposure problems.

Combustion Products

Combustion products are released by motor vehicle exhaust, tobacco smoke, and other sources, and contain airborne dust (see the previous section) along with potentially harmful gases such as carbon monoxide and nitrogen oxides.

Methodology

Direct-reading meters, detector tubes, and passive dosimeters are among the techniques most commonly used to measure carbon monoxide and nitrogen oxides.

Using the Results

Comparison with occupational standards

will reveal only whether an imminent danger exists. Any readings that are elevated above outdoor concentrations or background building levels may indicate a mixture of potentially irritating combustion products, especially if susceptible individuals are exposed.

Other Inorganic Gases

Although they are not routinely sampled in most IAQ studies, a variety of other gases may be evaluated where conditions warrant. Examples might include ammonia, ozone, and mercury.

Methodology

EPA, NIOSH, and ASTM references should be consulted for specific sampling techniques. Detector tubes or impinger methods are applicable in some cases.

Using the Results

No generalization can be applied to this diverse group of substances.

Appendix B:
HVAC Systems and Indoor Air Quality

This appendix provides information about specific HVAC system designs and components in relation to indoor air quality. It also serves as introductory material for building owners and managers who may be unfamiliar with the terminology and concepts associated with HVAC (heating, ventilating, and air conditioning) system design. Further detailed information can be found in ASHRAE manuals and guides and in some of the guidance developed by other trade and professional associations. (See *Guidelines of Care Developed by Trade Associations* in Section 5.) Additional information can be obtained using *Appendix G* or through discussion with your facility engineer.

BACKGROUND

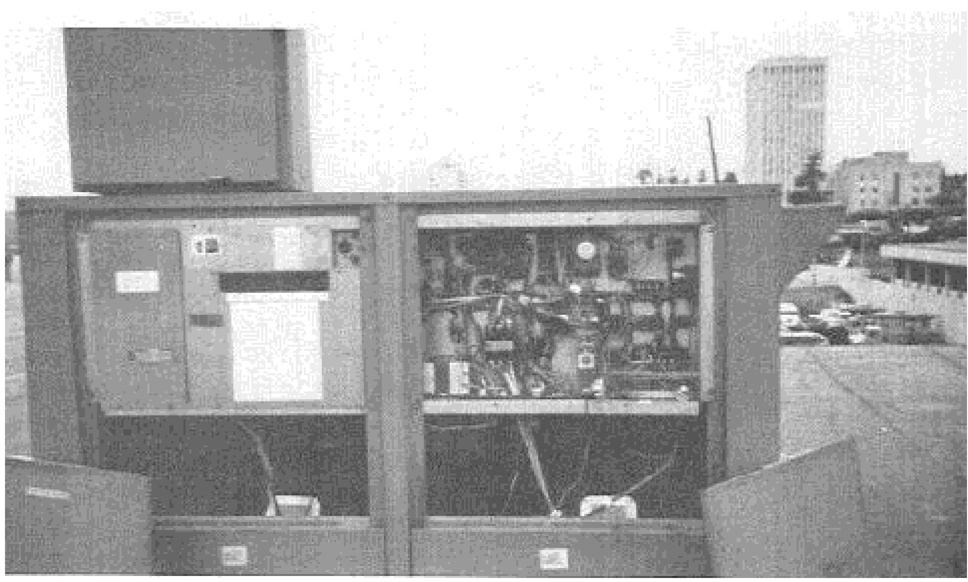
All occupied buildings require a supply of outdoor air. Depending on outdoor conditions, the air may need to be heated or cooled before it is distributed into the occupied space. As outdoor air is drawn into the building, indoor air is exhausted or allowed to escape (passive relief), thus removing air contaminants.

The term "HVAC system" is used to refer to the equipment that can provide heating, cooling, filtered outdoor air, and humidity control to maintain comfort conditions in a building. Not all HVAC systems are designed to accomplish all of these functions. Some buildings rely on only natural ventilation. Others lack mechanical cooling equipment (AC), and many function with little or no humidity control. The features of the HVAC system in a given building will depend on several variables, including:

- age of the design
- climate
- building codes in effect at the time of the design
- budget that was available for the project
- planned use of the building
- owners' and designers' individual preferences
- subsequent modifications

HVAC systems range in complexity from stand-alone units that serve individual rooms to large, centrally controlled systems serving multiple zones in a building. In large modern office buildings with heat gains from lighting, people, and equipment, interior spaces often require year-round cooling. Rooms at the perimeter of the same building (i.e., rooms with exterior walls, floors, or roof surfaces) may need to be heated and/or cooled as hourly or daily outdoor weather conditions change. In buildings over one story in height, perimeter areas at the lower levels also tend to experience the greatest uncontrolled air infiltration.

Working with the electrical components of an HVAC system involves the risk of electrocution and fire. A knowledgeable member of the building staff should oversee the inspection of the HVAC controls.



Some buildings use only natural ventilation or exhaust fans to remove odors and contaminants. In these buildings, thermal discomfort and unacceptable indoor air quality are particularly likely when occupants keep the windows closed because of extreme hot or cold temperatures. Problems related to underventilation are also likely when infiltration forces are weakest (i.e., during the "swing seasons" and summer months).

Modern public and commercial buildings generally use mechanical ventilation systems to introduce outdoor air during the occupied mode. Thermal comfort is commonly maintained by mechanically distributing conditioned (heated or cooled) air throughout the building. In some designs, air systems are supplemented by piping systems that carry steam or water to the building perimeter zones. As this document is concerned with HVAC systems in relation to indoor air quality, the remainder of this discussion will focus on systems that distribute conditioned air to maintain occupant comfort.

Roles of the HVAC System Operator and Facility Manager

The system operator(s) and facility manager(s) (or IAQ manager) are among the most significant factors in determining whether IAQ problems will occur in a properly designed, constructed, and commissioned HVAC system. HVAC systems require preventive maintenance and prompt repairs if they are to operate correctly and provide comfortable conditions. The operator(s) must have an adequate understanding of the overall system design and its limitations. The HVAC system capacity and distribution characteristics should be evaluated before renovations to the building, changes in its occupancy, or changes in the use of an area.

System operators must be able to respond appropriately to occupant complaints. For example, if an occupant complains that it is too cold or too hot and the observed (measured) conditions are outside of the ASHRAE comfort zone, then the HVAC system needs to be evaluated. Sometimes the problem can be relieved by fine tuning or repairing the HVAC system, but in some cases the system cannot perform as expected, and a long-term solution must be investigated.

TYPES OF HVAC SYSTEMS

Single Zone

A single air handling unit can only serve more than one building area if the areas served have similar heating, cooling, and ventilation requirements, or if the control system compensates for differences in heating, cooling, and ventilation needs among the spaces served. Areas regulated by a common control (e.g., a single thermostat) are referred to as zones. Thermal comfort problems can result if the design does not adequately account for differences in heating and cooling loads between rooms that are in the same zone. This can easily occur if:

- The cooling load in some area(s) within a zone changes due to an increased occupant population, increased lighting, or the introduction of new heat-producing equipment (e.g., computers, copiers).
- Areas within a zone have different solar exposures. This can produce radiant heat gains and losses that, in turn, create unevenly distributed heating or cooling needs (e.g., as the sun angle changes daily and seasonally).

Multiple Zone

Multiple zone systems can provide each zone with air at a different temperature by heating or cooling the airstream in each zone. Alternative design strategies involve delivering air at a constant temperature while varying the volume of airflow, or modulating room temperature with a supplementary system (e.g., perimeter hot water piping).

Constant Volume

Constant volume systems, as their name suggests, generally deliver a constant airflow to each space. Changes in space temperatures are made by heating or cooling the air or switching the air handling unit on and off, not by modulating the volume of air supplied. These systems often operate with a fixed minimum percentage of outdoor air or with an "air economizer" feature (described in the *Outdoor Air Control* discussion that follows).

Variable Air Volume

Variable air volume systems maintain thermal comfort by varying the amount of heated or cooled air delivered to each space, rather than by changing the air temperature. (However, many VAV systems also have provisions for resetting the temperature of the delivery air on a seasonal basis, depending on the severity of the weather). Overcooling or overheating can occur within a given zone if the system is not adjusted to respond to the load. Underventilation frequently occurs if the system is not arranged to introduce at least a minimum quantity (as opposed to percentage) of outdoor air as the VAV system throttles back from full airflow, or if the system supply air temperature is set too low for the loads present in the zone.

BASIC COMPONENTS OF AN HVAC SYSTEM

The basic components of an HVAC system that delivers conditioned air to maintain thermal comfort and indoor air quality are:

- outdoor air intake
- mixed-air plenum and outdoor air control
- air filter
- heating and cooling coils
- humidification and/or de-humidification equipment

TESTING AND BALANCING

Modern HVAC systems typically use sophisticated, automatic controls to supply the proper amounts of air for heating, cooling, and ventilation in commercial buildings. Problems during installation, operation, maintenance, and servicing the HVAC system could prevent it from operating as designed. Each system should be tested to ensure its initial and continued performance. In addition to providing acceptable thermal conditions and ventilation air, a properly adjusted and balanced system can also reduce operating costs and increase equipment life.

Testing and balancing involves the testing, adjusting, and balancing of HVAC system components so that the entire system provides airflows that are in accordance with the design specifications. Typical components and system parameters tested include:

- all supply, return, exhaust, and outdoor airflow rates
- control settings and operation
- air temperatures
- fan speeds and power consumption
- filter or collector resistance

The typical test and balance agency or contractor coordinates with the control contractor to accomplish three goals: verify and ensure the most effective system operation within the design specifications, identify and correct any problems, and ensure the safety of the system.

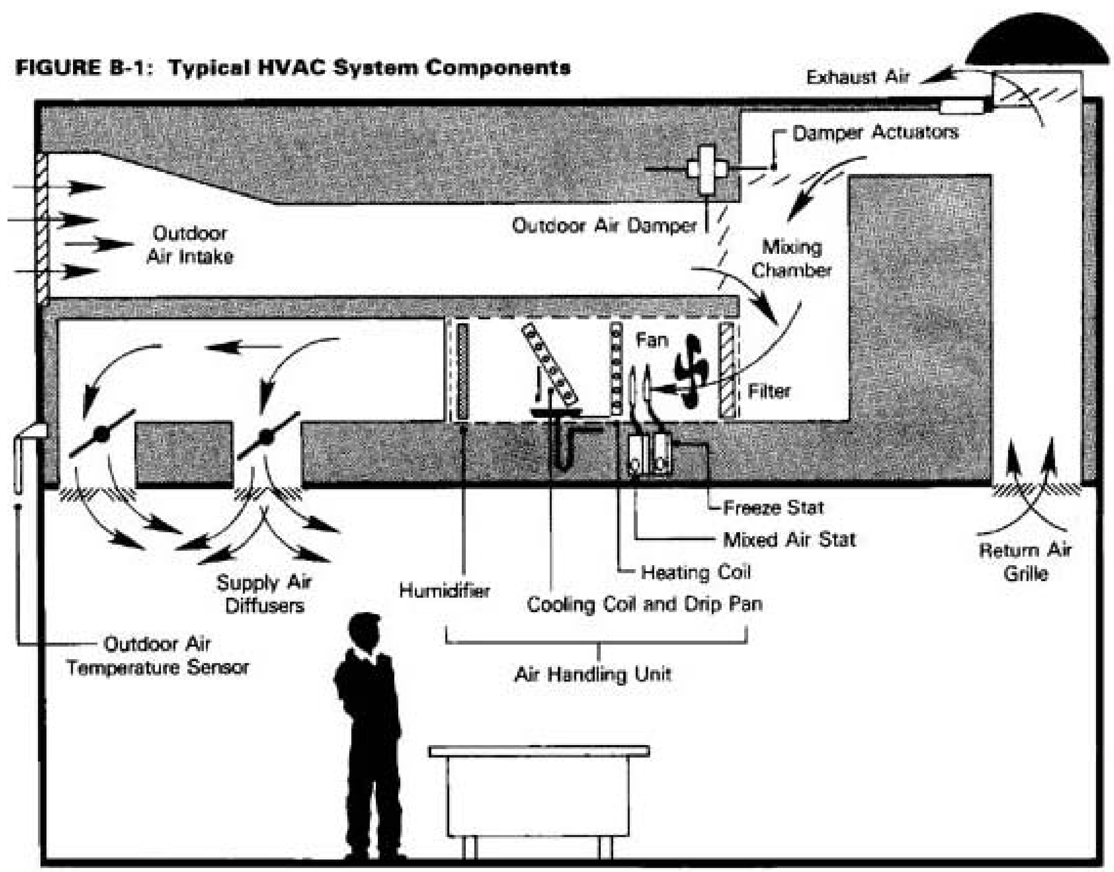
A test and balance report should provide a complete record of the design, preliminary measurements, and final test data. The report should include any discrepancies between the test data and the design specifications, along with reasons for those discrepancies. To facilitate future performance checks and adjustments, appropriate records should be kept on all damper positions, equipment capacities, control types and locations, control settings and operating logic, airflow rates, static pressures, fan speeds, and horsepowers.

Testing and balancing of existing building systems should be performed whenever there is reason to believe the system is not functioning as designed or when current records do not accurately reflect the actual operation of the system. The Associated Air Balance Council recommends the following guidelines in determining whether testing and balancing is required:

- When space has been renovated or changed to provide for new occupancy.
- When HVAC equipment has been replaced or modified.
- When control settings have been readjusted by maintenance or other personnel.
- After the air conveyance system has been cleaned.
- When accurate records are required to conduct an IAQ investigation.
- When the building owner is unable to obtain design documents or appropriate air exchange rates for compliance with IAQ standards or guidelines.

Because of the diversity of system types and the interrelationship of system components, effective balancing requires a skilled technician with the proper experience and instruments. Due to the nature of the work, which involves the detection and remediation of problems, it is recommended that an independent test and balance contractor be used and that this contractor report directly to the building owner, facility manager, or IAQ manager.

FIGURE B-1: Typical HVAC System Components



Courtesy Terry Brennan
Camroden Associates
Oriskny, N.Y.

- supply fan
- ducts
- terminal device
- return air system
- exhaust or relief fans and air outlet
- self-contained heating or cooling unit
- control
- boiler
- cooling tower
- water chiller

The following discussion of these components (each of which may occur more than once in any total HVAC system) emphasizes features that affect indoor air quality. It may be helpful to refer to this section when using the **HVAC Checklists**.

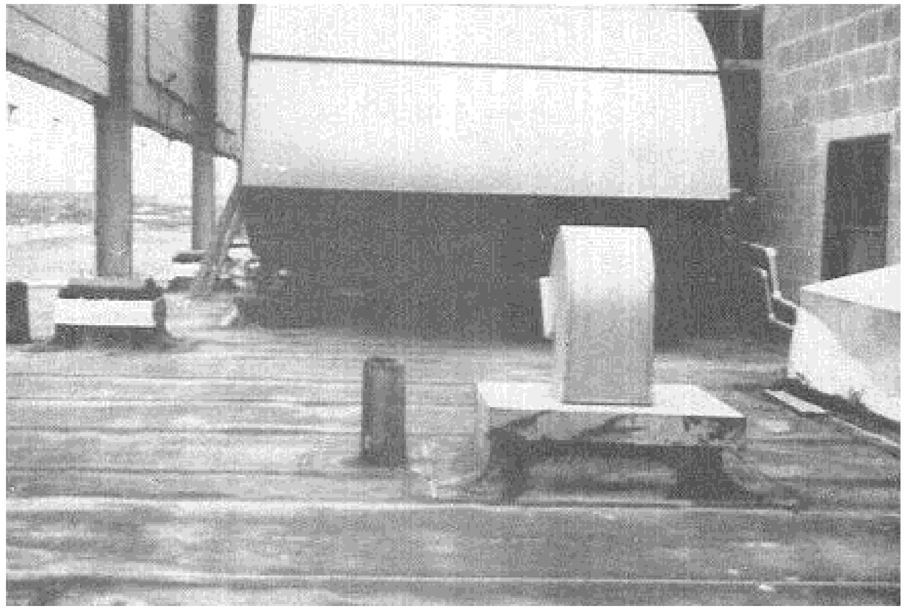
The illustration above shows the general relationship between many of these components; however, many variations are possible.

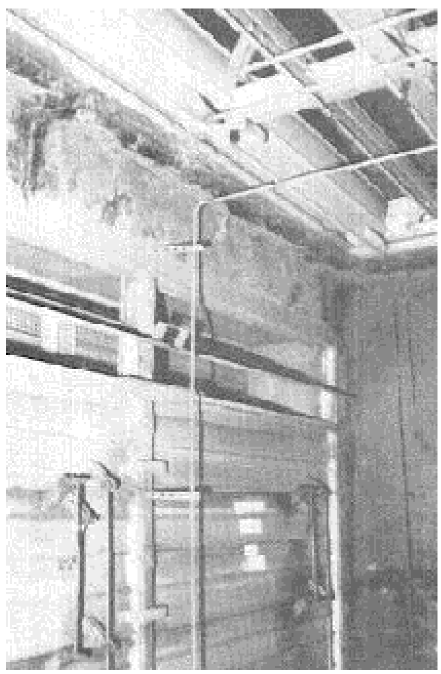
Outdoor Air Intake

Building codes require the introduction of outdoor air for ventilation in most buildings. Most non-residential air handlers are designed with an outdoor air intake on the return side of the ductwork. Outdoor air introduced through the air handler can be filtered and conditioned (heated or cooled) before distribution. Other designs may introduce outdoor air through air-to-air heat exchangers and operable windows.

Indoor air quality problems can be produced when contaminants enter a building with the outdoor air. Rooftop or wall-mounted air intakes are sometimes located adjacent to or downwind of building exhaust outlets or other contaminant sources. Problems can also result if debris (e.g., bird droppings) accumulates at the intake, obstructing airflow and potentially introducing microbiological contaminants.

If more air is exhausted than is introduced through the outdoor air intake, then outdoor air will enter the building at any leakage sites in the shell. Indoor air quality problems can occur if the leakage site is a door to a loading dock, parking garage, or some other area associated with pollutants.





Above: *The air intake in the background is located too close to the sanitary vents (the straight pipes to the left and in the center foreground) and the bathroom exhaust vent (next to the sanitary vent on the right side).* ***Below:*** *The return air dampers in this mixed-air plenum are open (top), but the outdoor air damper (left) is almost completely closed. Complaints in the building indicate that under-ventilation is a problem.*

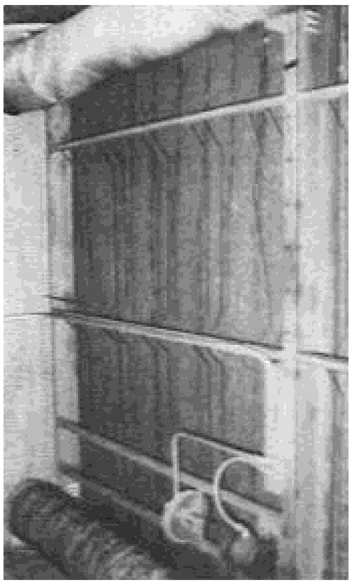
Mixed-Air Plenum and Outdoor Air Controls

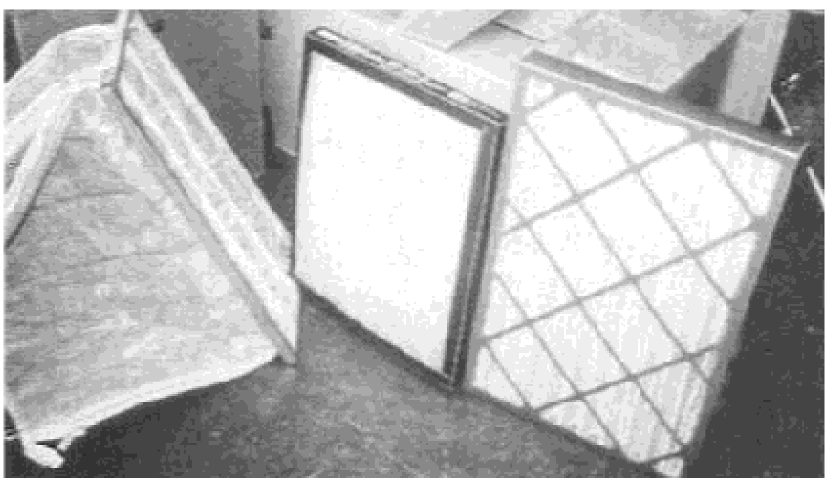
Outdoor air is mixed with return air (air that has already circulated through the HVAC system) in the mixed-air plenum of an air handling unit. Indoor air quality problems frequently result if the outdoor air damper is not operating properly (e.g., if the system is not designed or adjusted to allow the introduction of sufficient outdoor air for the current use of the building. The amount of outdoor air introduced in the occupied mode should be sufficient to meet needs for ventilation and exhaust make-up. It may be fixed at a constant volume or may vary with the outdoor temperature.

When dampers that regulate the flow of outdoor air are arranged to modulate, they are usually designed to bring in a minimum amount of outdoor air (in the occupied mode) under extreme outdoor temperature conditions and to open as outdoor temperatures approach the desired indoor temperature. Systems that use outdoor air for cooling are called “air economizer cooling” systems. Air economizer systems have a mixed air temperature controller and thermostat that are used to blend return air (typically at 74°F) with outdoor air to reach a mixed air temperature of 55° to 65°F. (Mixed air temperature settings above 65°F may lead to the introduction of insufficient quantities of outdoor air for office space use.) The mixed air is then further heated or cooled for delivery to the occupied spaces.

Air economizer systems have a sensible or enthalpy control that signals the outdoor air damper to go to the minimum position when it is too warm or humid outdoors. Note that economizer cycles which do not provide dehumidification may produce discomfort even when the indoor temperature is the same as the thermostat setting.

If outdoor air make-up and exhaust are balanced, and the zones served by each air handler are separated and well defined, it is possible to estimate the minimum flow of outdoor air to each space and compare it to ventilation standards such as ASHRAE 62-1989. Techniques used for this evaluation include the direct measurement of the outdoor air at the intake and the calculation of the percentage of outdoor air by a temperature or CO_2 balance. Carbon dioxide measured in an occupied space is also an indicator of ventilation adequacy. Some investigators use tracer gases to assess ventilation quantities and airflow patterns. There are specific methods for each of these assessments. See *Appendix A* for more information.





Proper air filtration can play an important role in protecting the rest of the HVAC system and in maintaining good indoor air quality in occupied spaces. Air filters should be selected and maintained to provide maximum filtration, while not overtaxing the supply fan capability or leading to "blow out" situations with no air filtration. Shown above are roll filter (top) and bag, panel, and pleated filters (below).

Many HVAC designs protect the coils by closing the outdoor air damper if the airstream temperature falls below the setpoint of a freezestat. Inadequate ventilation can occur if a freezestat trips and is not reset, or if the freezestat is set to trip at an excessively high temperature. Stratification of the cold outdoor air and warmer return air in the mixing plenums is a common situation, causing nuisance tripping of the freezestat. Unfortunately, the remedy often employed to prevent this problem is to close the outdoor air damper. Obviously, solving the problem in this way can quickly lead to inadequate outdoor air in occupied parts of the building.

Air Filters

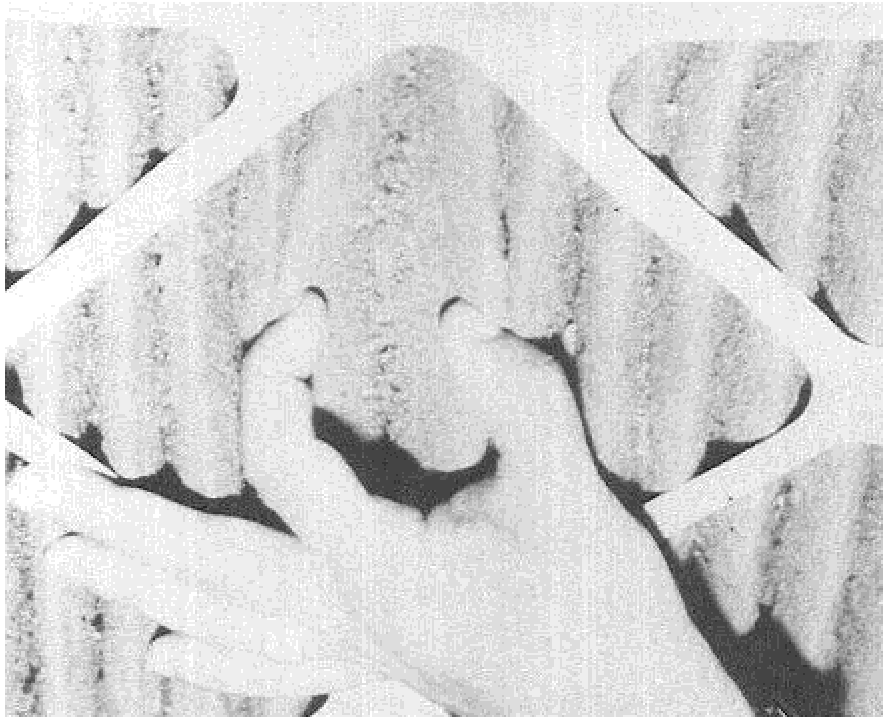
Filters are primarily used to remove particles from the air. The type and design of filter determine the efficiency at removing particles of a given size and the amount of energy needed to pull or push air through the filter. Filters are rated by different standards and test methods such as dust spot and arrestance which measure different aspects of performance. See the discussion of ASHRAE Standard 52-76 on page 138 of this appendix.

Low efficiency filters (ASHRAE Dust Spot rating of 10% to 20% or less) are often used to keep lint and dust from clogging the heating and cooling coils of a system. In order to maintain clean air in occupied spaces, filters must also remove bacteria, pollens, insects, soot, dust, and dirt with an efficiency suited to the use of the building. Medium efficiency filters (ASHRAE Dust Spot rating of 30% to

60%) can provide much better filtration than low efficiency filters. To maintain the proper airflow and minimize the amount of additional energy required to move air through these higher efficiency filters, pleated-type extended surface filters are recommended. In buildings that are designed to be exceptionally clean, the designers may specify the equipment to utilize both a medium efficiency pre-filter and a high efficiency extended surface filter (ASHRAE Dust Spot rating of 85% to 95%). Some manufacturers recommend high efficiency extended surface filters (ASHRAE Dust Spot rating of 85%) without pre-filters as the most cost effective approach to minimizing energy consumption and maximizing air quality in modern HVAC VAV systems that serve office environments.

Air filters, whatever their design or efficiency rating, require regular maintenance (cleaning for some and replacement for most). As a filter loads up with particles, it becomes more efficient at particle removal but increases the pressure drop through the system, therefore reducing airflow. Filter manufacturers can provide information on the pressure drop through their products under different conditions. Low efficiency filters, if loaded to excess, will become deformed and even "blow out" of their filter rack. When filters blow out, bypassing of unfiltered air can lead to clogged coils and dirty ducts. Filtration efficiency can be seriously reduced if the filter cells are not properly sealed to prevent air from bypassing.

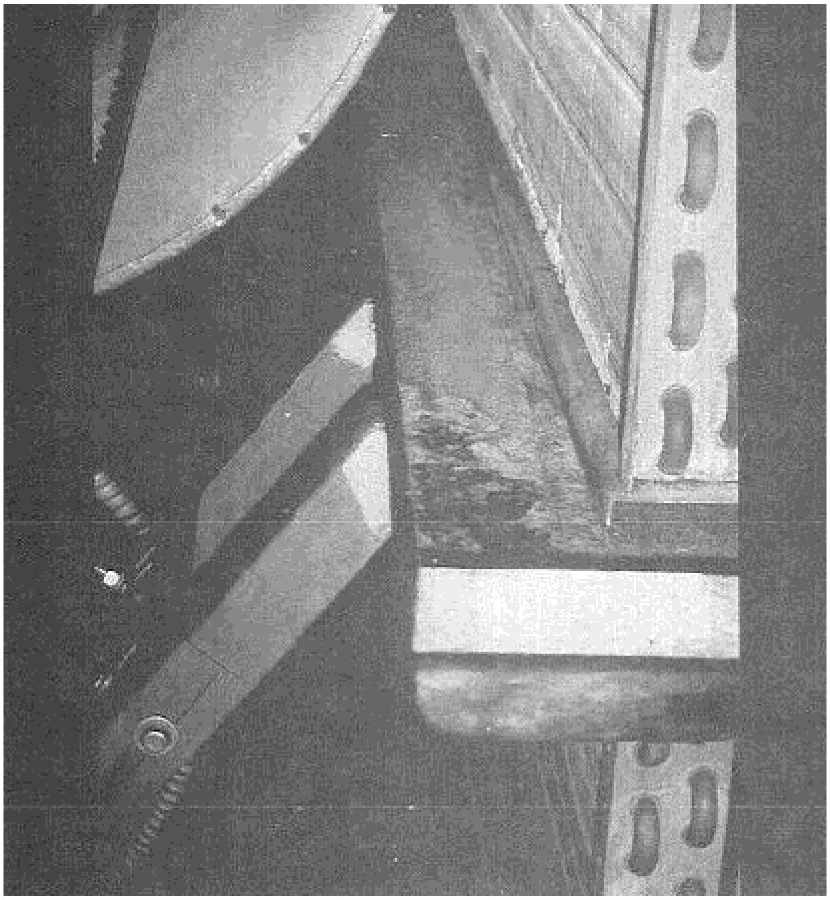
Filters should be selected for their ability to protect both the HVAC system components and general indoor air quality. In many buildings, the best choice is a medium efficiency, pleated filter because these filters have a higher removal efficiency than low efficiency filters, yet they will last without clogging for longer than high efficiency filters.



Pleated medium efficiency filters are often preferred over low efficiency filters because they offer added protection to both the HVAC equipment and to indoor air quality, yet they do not clog as easily as high efficiency filters. Medium efficiency filters do need routine maintenance, however, which the filter in this photo did not receive.

Choice of an appropriate filter and proper maintenance are important to keeping the ductwork clean. If dirt accumulates in ductwork and if the relative humidity reaches the dewpoint (so that condensation occurs), then the nutrients and moisture may support the growth of microbiologicals. Attention to air filters is particularly important in HVAC systems with acoustical duct liner, which is frequently used in air handler fan housings and supply ducts to reduce sound transmission and provide thermal insulation. Areas of duct lining that have become contaminated with microbiological growth must be replaced. (See later discussion of ducts and duct cleaning .) Sound reduction can also be accomplished with the use of special duct-mounted devices such as attenuators or with active electronic noise control.

Air handlers that are located in difficult-to-access places (e.g., in places which require ladders for access, have inconvenient access doors to unbolt, or are located on roofs with no roof hatch access) will be



Without proper installation and maintenance, rust and corrosion may accumulate in condensate pans under heating and cooling coils. The rust in the pan indi-cates that it was installed without a pitch or was pitched in the wrong direction, so that water did not drain out properly.

more likely to suffer from poor air filter maintenance and overall poor maintenance. Quick release and hinged access doors for maintenance are more desirable than bolted access panels.

Filters are available to remove gases and volatile organic contaminants from ventilation air; however, these systems are not generally used in normal occupancy buildings. In specially designed HVAC systems, permanganate oxidizers and activated charcoal may be used for gaseous removal filters. Some manufacturers offer "partial bypass" carbon filters and carbon impregnated filters to reduce volatile organics in the ventilation air of office environments. Gaseous filters must be regularly maintained (replaced or regenerated) in order for the system to continue to operate effectively.

Heating and Cooling Coils

Heating and cooling coils are placed in the airstream to regulate the temperature of the air delivered to the space. Malfunctions of the coil controls can result in thermal discomfort. Condensation on under-insulated pipes and leakage in piped systems will often create moist conditions conducive to the growth of molds, fungus, and bacteria.

During the cooling mode (air conditioning), the cooling coil provides dehumidification as water condenses from the airstream. Dehumidification can only take place if the chilled fluid is maintained at a cold enough temperature (generally below 45°F for water). Condensate collects in the drain pan under the cooling coil and exits via a deep seal trap. Standing water will accumulate if the drain pan system has not been designed to drain completely under all operating conditions (sloped toward the drain and properly trapped). Under these conditions, molds and bacteria will proliferate unless the pan is cleaned frequently.

It is important to verify that condensate lines have been properly trapped and are charged with liquid. An improperly trapped line can be a source of contamination, depending on where the line terminates. A properly installed trap could also be a source, if the water in the trap evaporates and allows air to flow through the trap into the conditioned air.

During the heating mode, problems can occur if the hot water temperature in the heating coil has been set too low in an attempt to reduce energy consumption. If enough outdoor air to provide sufficient ventilation is brought in, that air may not be heated sufficiently to maintain thermal comfort or, in order to adequately condition the outdoor air, the amount of outdoor air may be reduced so that there is insufficient outdoor air to meet ventilation needs.

Humidification and Dehumidification Equipment

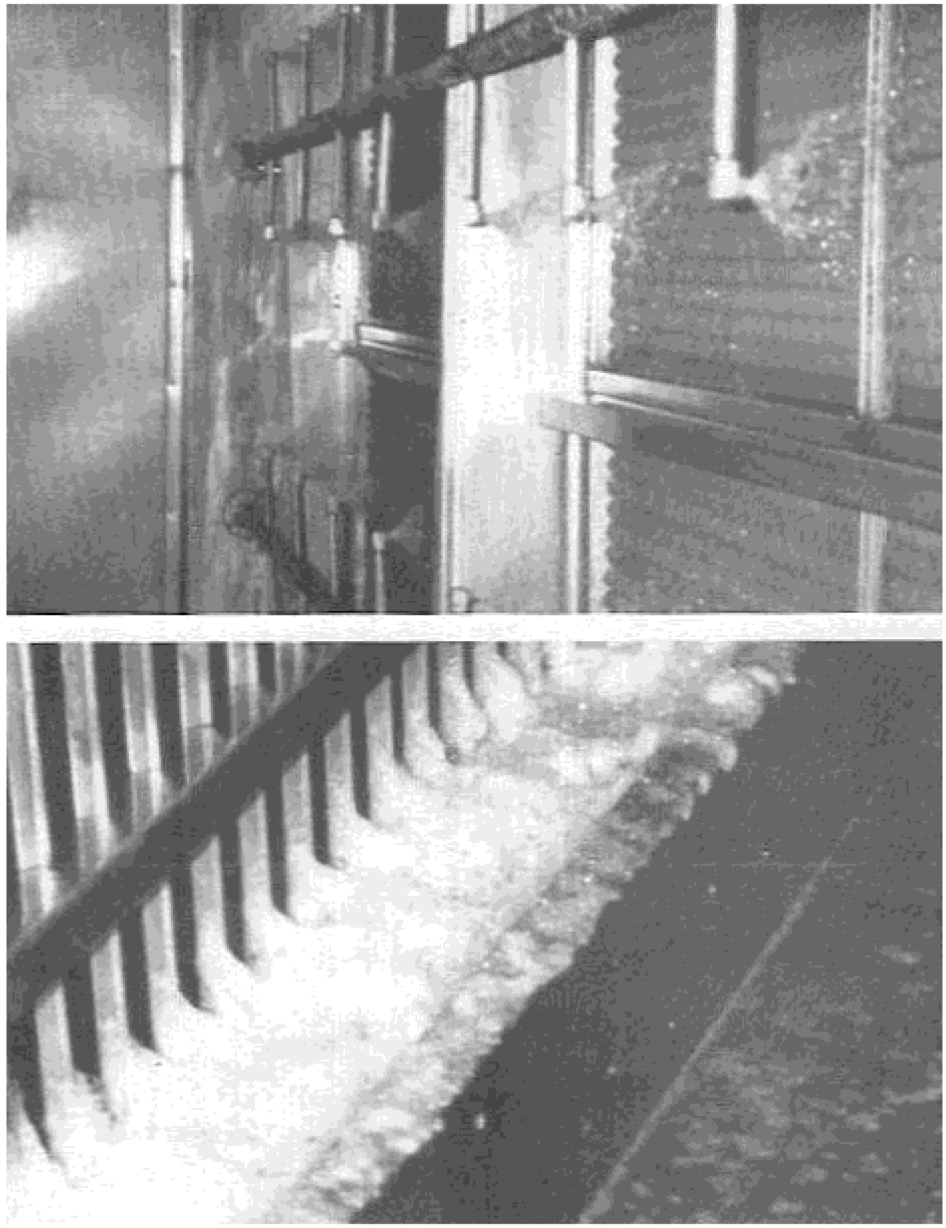
In some buildings (or zones within buildings), there are special needs that warrant the strict control of humidity (e.g., operating rooms, computer rooms). This control is most often accomplished by adding humidification or dehumidification equipment and controls. In office facilities, it is generally preferable to keep relative humidities above 20% or 30% during the heating season and below 60% during the cooling season. ASHRAE Standard 55-1981 provides guidance on acceptable temperature and humidity conditions. (See also the discussion of humidity levels in *Section 6*.)

The use of a properly designed and operated air conditioning system will generally keep relative humidities below 60% RH during the cooling season, in office facilities with normal densities and loads. (See the previous discussion of the cooling coil.)

Office buildings in cool climates that have high interior heat gains, thermally efficient envelopes (e.g., insulation), and economizer cooling may require humidification to maintain relative humidity within the comfort zone. When humidification is needed, it must be added in a manner that prevents the growth of microbiologicals within the ductwork and air handlers.

Steam humidifiers should utilize clean steam, rather than treated boiler water, so that occupants will not be exposed to chemicals. Systems using media other than clean steam must be rigorously maintained in accordance with the manufacturer's recommended procedures to reduce the likelihood of microbiological growth.

Mold growth problems are more likely if the humidistat setpoint located in the occupied space is above 45%. The high limit humidistat, typically located in the ductwork downstream of the point at



Above: Occupants of this building complained of an inter-mittant fish tank odor. An investigation showed that this water spray humidifi-cation system is regularly maintained. The coils are washed roughly every two weeks using fresh tap water, eliminating the need for any use of algacides. Below: Further investigation identified the fact that the maintenance practice was causing the odor problem. This picture of the downstream side of the coils was taken one day after the washing. A high pressure stream of water caused algae in the water to foam and float for several days, coinciding with the occupant complaints.

DUCT LEAKAGE

Leakage of air from ducts can cause or exacerbate air quality problems, in addition to wasting energy. In general, sealed duct systems specified with a leakage rate of less than 3% will have a superior life cycle cost analysis and reduce the likelihood of problems associated with leaky ductwork. Examples of excessive duct leakage leading to problems include:

- leakage of light troffer-type diffusers at the diffuser/light fixture interface when they are installed in a return plenum. Such leakage has been known to cause gross short-circuiting between supply and return, wasting much of the conditioned air. If the "room" thermostat is located in the return plenum, the room can be very uncomfortable while the temperature in the plenum is operating at the control setpoint.
- leakage of supply ductwork due to loose-fitting joints and connections or "blow outs" of improperly fabricated seams
- leakage of return ducts located in crawl spaces or below slabs, allowing soil gases and molds to enter the ductwork

which water vapor is added, is generally set at 70% to avoid condensation (with a potential for subsequent mold growth) in the ductwork. Adding water vapor to a building that was not designed for humidification can have a negative impact on the building structure and the occupants' health, if condensation occurs on cold surfaces or in wall or roof cavities.

Supply Fans

After passing through the coil section where heat is either added or extracted, air moves through the supply fan chamber and the distribution system. Air distribution systems commonly use ducts that are constructed to be relatively airtight. Elements of the building construction can also serve as part of the air distribution system (e.g., pressurized supply plenums or return air plenums located in the cavity space above the ceiling tiles and below the deck of the floor above). Proper coordination of fan selection and duct layout during the building design and construction phase and ongoing maintenance of mechanical components, filters, and controls are all necessary for effective air delivery.

Fan performance is expressed as the ability to move a given quantity of air (cubic feet per minute or cfm) at a given resistance or static pressure (measured in inches of water column). Airflow in ductwork is determined by the size of the duct opening, the resistance of the duct configuration, and the velocity of the air through the duct. The static pressure in a system is calculated using factors for duct length, speed of air movement and changes in the direction of air movement.

It is common to find some differences between the original design and the final installation, as ductwork must share limited space with structural members and other "hidden" elements of the building system (e.g., electrical conduit, plumbing pipes). Air distribution problems can occur, particularly at the end of duct runs, if departures from the original design increase the friction in the system to a point that approaches the limit of fan performance. Inappropriate use of long runs of flexible ducts with sharp bends also causes excessive friction. Poor system balancing (adjustment) is another common cause of air distribution problems.

Dampers are used as controls to restrict airflow. Damper positions may be relatively fixed (e.g., set manually during system testing and balancing) or may change in response to signals from the control system. Fire and smoke dampers can be triggered to respond to indicators such as high temperatures or signals from smoke detectors. If a damper is designed to modulate, it should be checked during inspections to see that it is at the proper setting. ASHRAE and the Associated Air Balance Council both provide guidance on proper intervals for testing and balancing.

Ducts

The same HVAC system that distributes conditioned air throughout a building air can distribute dust and other pollutants, including biological contaminants. Dirt or dust accumulation on any components of an air handling system — its cooling coils, plenums, ducts, and equipment housing — may lead to contamination of the air supply.

There is widespread agreement that building owners and managers should take great precautions to prevent dirt, high humidity, or moisture from entering the ductwork; there is less agreement at present about when measures to clean up are appropriate or how effective cleaning techniques are at making long-term improvements to the air supply or at reducing occupant complaints.

The presence of dust in ductwork does not necessarily indicate a current microbiological problem. A small amount of dust on duct surfaces is normal and to be expected. Special attention should be given to trying to find out if ducts are contaminated only where specific problems are present, such as: water damage or biological growth observed in ducts, debris in ducts that restricts airflow, or dust discharging from supply diffusers.

Problems with dust and other contamination in the ductwork are a function of filtration efficiency, regular HVAC system maintenance, the rate of airflow, and good housekeeping practices in the occupied space. Problems with biological pollutants can be prevented by minimizing dust and dirt build-up, promptly repairing leaks and water damage, preventing moisture accumulation in the components that are supposed to be dry, and cleaning the components such as the drip pans that collect and drain water.

In cases where sheet metal ductwork has become damaged or water-soaked, building owners will need to undertake clean-up or repair procedures. For example, in cases where the thermal liner or fiberboard has become water-soaked, building managers will need to replace the affected areas. These procedures should be scheduled and performed in a way that does not expose building occupants to increased levels of pollutants and should be carried out by experienced workers. Correcting theproblems that allowed the ductwork to become contaminated in the first place is important. Otherwise, the corrective action will only be temporary.

The porous surface of fibrous glass duct liner presents more surface area (which can trap dirt and subsequently collect water) than sheet metal ductwork. It is therefore particularly important to pay attention to the proper design, installation, filtration, humidity, and maintenance of ducts that contain porous materials. In addition, techniques developed for cleaning unlined metal ducts often are not suitable for use with fibrous glass thermal liner or fiberboard. Such ducts may require a special type of cleaning to maintain the integrity of the duct (i.e., no heavy brushing tools that might fray the inner lining) while removing dirt and debris.

More research on both the efficacy and the potential for unintended exposures to building occupants from various cleaning techniques is needed before firm guidance can be provided regarding duct cleaning.

Pay attention to worker safety when working with air handling systems including during duct cleaning. Any worker who may potentially breathe duct contaminants or biocides should wear suitable protective breathing apparatus. Workers who are doing the duct cleaning should be encouraged to also look for other types of problems, such as holes or gaps in the ducts that could allow contaminants to enter the ventilation airstream.

Building managers can obtain more information on the issue of HVAC contamination and cleaning from the professional standards developed by some trade associations (See *Guidelines of Care Developed by Professional and Trade Associations* in *Section 5* and refer to *Appendix G* for a list of organizations with expertise and materials on these issues.)

PRELIMINARY RECOMMENDATIONS ON DUCT CLEANING

1. Any duct cleaning should be scheduled during periods when the building is unoccupied to prevent exposure to chemicals and loosened particles.

The air handling unit should not be used during the cleaning or as an air movement device for the cleaning process. The National Air Duct Cleaning Association recommends that the system should be run to allow at least eight air changes in the occupied space when duct cleaning has been completed.

2. Negative air pressure that will draw pollutants to a vacuum collection system should be maintained at all times in the duct cleaning area to prevent migration of dust dirt, and contaminants into occupied areas.

Where possible, use vacuum equipment or fans during cleaning and sanitizing to make sure that cleaning vapors are exhausted to the outside and do not enter the occupied space.

3. If it is determined that the ductwork should be cleaned, careful attention must be given to protecting the ductwork.

When gaining access to sheet metal ducts for cleaning purposes, it is essential to seal the access hole properly in order to maintain the integrity of the HVAC system. Access doors are recommended if the system is to be cleaned periodically, and all access holes should be identified on the building's mechanical plans.

Particular attention is warranted when cutting fibrous glass ducts, and manufacturers' recommended procedures for sealing should be followed stringently. Use existing duct system openings where possible because it is difficult to repair the damage caused by cutting new access entries into the ductwork. Large, high volume vacuum equipment should only be used with extreme care because high negative pressure together with limited airflow can collapse ducts.

4. Duct cleaning performed with high velocity airflow (i.e., greater than 6,000 cfm) should include gentle, well-controlled brushing of duct surfaces or other methods to dislodge dust and other particles.

Duct cleaning that relies only on a high velocity airflow through the ducts is not likely to achieve satisfactory results because the flow rate at the duct surface remains too low to remove many particles.

5. Only HEPA filtered (high-efficiency particle arrestor) vacuuming equipment should be used if the vacuum collection unit is inside the occupied space.

Conventional vacuuming equipment may discharge extremely fine particulate matter back into the atmosphere, rather than collecting it. Duct cleaning equipment that draws the dust and dirt into a collection unit outside the building is also available. People should not be allowed to remain in the immediate vicinity of these collection units.

6. If biocides are to be used, then select only products registered by EPA for such use, use the products according to the manufacturer's directions, and pay careful attention to the method of application.

At present, EPA accepts claims and therefore registers antimicrobials for use only as sanitizers, not disinfectants or sterilizers in HVAC systems. (See *Appendix F* for definitions of antimicrobials.) There is some question about whether there are any application techniques that will deposit a sufficient amount of the biocide to kill bacteria, germs, or other biologicals that may be present. Materials such as deodorizers that temporarily eliminate odors caused by microorganisms provide only a fresh smell, and are not intended to provide real control of microbiological contaminants.

7. Use of sealants to cover interior ductwork surfaces is not recommended.

No application techniques have been demonstrated to provide a complete or long-term barrier to microbiological growth, nor have such materials been evaluated for their potential health effects on occupants. In addition, using sealants alters the surface burning characteristics of the duct material and may void the fire safety rating of the ductwork.

8. Careful cleaning and sanitizing of any parts of coils and drip pans can reduce microbiological pollutants.

Prior to using sanitizers, deodorizers, or any cleansing agents, carefully read the directions on the product label. Once cleaned, these components should be thoroughly rinsed and dried to prevent exposure of building occupants to the cleaning chemicals.

9. Water-damaged or contaminated porous materials in the ductwork or other air handling system components should be removed and replaced.

Even when such materials are thoroughly dried, there is no way to guarantee that all microbial growth has been eliminated.

10. After the duct system has been cleaned and restored to use, a preventive maintenance program will prevent the recurrence of problems.

Such a program should include particular attention to the use and maintenance of adequate filters, control of moisture in the HVAC system, and periodic inspection and cleaning of HVAC system components. (See discussion of *Preventive Maintenance* on page 36 in *Section 5*.)

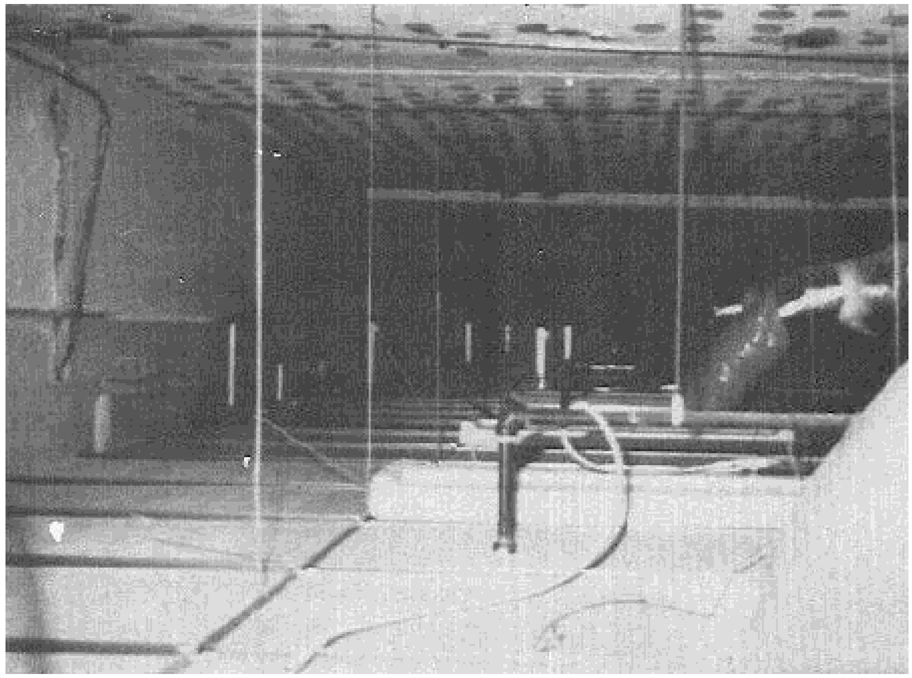
Terminal Devices

Thermal comfort and effective contaminant removal demand that air delivered into a conditioned space be properly distributed within that space. Terminal devices are the supply diffusers, return and exhaust grilles, and associated dampers and controls that are designed to distribute air within a space and collect it from that space. The number, design, and location (ceiling, wall, floor) of terminal devices are very important. They can cause a HVAC system with adequate capacity to produce unsatisfactory results, such as drafts, odor transport, stagnant areas, or short-circuiting.

Occupants who are uncomfortable because of distribution deficiencies (drafts, odor transport, stagnant air, or uneven temperatures) often try to compensate by adjusting or blocking the flow of air from supply outlets. Adjusting system flows without any knowledge of the proper design frequently disrupts the proper supply of air to adjacent areas. Distribution problems can also be produced if the arrangement of movable partitions, shelving, or other furnishings interferes with airflow. Such problems often occur if walls are moved or added without evaluating the expected impact on airflows.

Return Air Systems

In many modern buildings the above-ceiling space is utilized for the unducted passage of return air. This type of system approach often reduces initial HVAC system costs, but requires that the designer, maintenance personnel, and contractors obey strict guidelines related to life and safety codes (e.g., building codes) that must be followed for materials and devices that are located in the plenum. In addition, if a ceiling plenum is used for the collection of return air, openings into the ceiling plenum created by the removal of ceiling tiles will disrupt airflow patterns. It is particularly important to maintain the integrity of the ceiling and adjacent walls in areas that are designed to be exhausted, such as supply closets, bathrooms, and chemical storage areas.



Return air is frequently carried through non-ducted plenums. It is more difficult to control leakage of pollutants into or out of this type of return air system than a ducted system.

After return air enters either a ducted return air grille or a ceiling plenum, it is returned to the air handlers. Some systems utilize return fans in addition to supply fans in order to properly control the distribution of air. When a supply and return fan are utilized, especially in a VAV system, their operation must be coordinated in order to prevent under- or over-pressurization of the occupied space or overpressurization of the mixing plenum in the air handler.

Exhausts, Exhaust Fans, and Pressure Relief

Most buildings are required by law (e.g., building or plumbing codes) to provide for exhaust of areas where contaminant sources are strong, such as toilet facilities, janitorial closets, cooking facilities, and parking garages. Other areas where exhaust is frequently recommended but may not be legally required include: reprographics areas, graphic arts facilities, beauty salons, smoking lounges, shops, and any area where contaminants are known to originate.

For successful confinement and exhaust of identifiable sources, the exhausted area must be maintained at a lower overall pressure than surrounding areas. Any area that is designed to be exhausted must also be isolated (disconnected) from the return air system so that contaminants are not transported to another area of the building.

In order to exhaust air from the building, make-up air from outdoors must be brought into the HVAC system to keep the building from being run under negative pressure. This make-up air is typically drawn in at the mixed air plenum as described earlier and distributed within the building. For exhaust systems to function properly, the make-up air must have a clear path to the area that is being exhausted.

It is useful to compare the total cfm of powered exhaust to the minimum quantity of mechanically-introduced outdoor air. To prevent operating the building under negative pressures (and limit the amount of unconditioned air brought into the building by infiltration), the amount of make-up air drawn in at the air handler should always be slighter greater than the total amount of relief air, exhaust air, and air exfiltrating through the building shell. Excess make-up air is generally relieved at an exhaust or relief outlet in the HVAC system, especially in air economizer systems. In addition to reducing the effects of unwanted infiltration, designing and operating a building at slightly positive or neutral pressures will reduce the rate of entry of soil gases when the systems are operating. For a building to actually operate at a slight positive pressure, it must be tightly constructed (e.g., specified at less than one-half air change per hour at 0.25 pascals). Otherwise unwanted exfiltration will prevent the building from ever achieving a neutral or slightly positive pressure.

Self-Contained Units

In some designs, small decentralized units are used to provide cooling or heating to interior or perimeter zones. With the exception of induction units, units of this type seldom supply outdoor air. They are typically considered a low priority maintenance item. If self-contained units are overlooked during maintenance, it is not unusual for them to become a significant source of contaminants, especially for the occupants located nearby.

Controls

HVAC systems can be controlled manually or automatically. Most systems are controlled by some combination of manual and automatic controls. The control system can be used to switch fans on and off, regulate the temperature of air within the conditioned space, or modulate airflow and pressures by controlling fan speed and damper settings. Most large buildings use automatic controls, and many have very complex and sophisticated systems. Regular maintenance and calibration are required to keep controls in good operating order. All programmable timers and switches should have “battery backup” to reset the controls in the event of a power failure.

Local controls such as room thermostats must be properly located in order to maintain thermal comfort. Problems can result from:

- thermostats located outside of the occupied space (e.g., in return plenum)
- poorly designed temperature control zones (e.g., single zones that combine areas with very different heating or cooling loads)
- thermostat locations subject to drafts or to radiant heat gain or loss (e.g., exposed to direct sunlight)

- thermostat locations affected by heat from nearby equipment

To test whether or not a thermostat is functioning properly, try setting it to an extreme temperature. This experiment will show whether or not the system is responding to the signal in the thermostat, and also provides information about how the HVAC system may perform under extreme conditions.

Boilers

Like any other part of the HVAC system, a boiler must be adequately maintained to operate properly. However, it is particularly important that combustion equipment operate properly to avoid hazardous conditions such as explosions or carbon monoxide leaks, as well as to provide good energy efficiency. Codes in most parts of the country require boiler operators to be properly trained and licensed.

Both ASME and ASHRAE have made recommendations of how much combustion air is needed for fuel burning appliances.

Elements of boiler operation that are particularly important to indoor air quality and thermal comfort include:

- Operation of the boiler and distribution loops at a high enough temperature to supply adequate heat in cold weather.
- Maintenance of gaskets and breeching to prevent carbon monoxide from escaping into the building.
- Maintenance of fuel lines to prevent any leaks that could emit odors into the building.
- Provision of adequate outdoor air for combustion.
- Design of the boiler combustion exhaust to prevent re-entrainment, (especially from short boiler stacks, or into multi-story buildings that were added after the boiler plant was installed).

It is important to determine periodically whether the HVAC controls are correctly calibrated. In addition, time clocks must be checked to see if they are properly set and running. Power failures frequently cause time clocks to be out of adjustment.

Modern office buildings tend to have much smaller capacity boilers than older buildings because of advances in energy efficiency. In some buildings, the primary heat source is waste heat recovered from the chiller (which operates year-round to cool the core of the building).

Cooling Towers

Maintenance of a cooling tower ensures proper operation and keeps the cooling tower from becoming a niche for breeding pathogenic bacteria, such as *Legionella* organisms. Cooling tower water quality must be properly monitored and chemical treatments used as necessary to minimize conditions that could support the growth of significant amounts of pathogens. Proper maintenance may also entail physical cleaning (by individuals using proper protection) to prevent sediment accumulation and installing drift eliminators.

FIGURE B-2: Selected Ventilation Recommendations

Application		Occupancy (people/1000 ft²)	Cfm/person	Cfm/ft²
Food and Beverage Service	Dining rooms	70	20	
	Cafeteria, fast food	100	20	
	Bars, cocktail lounges	100	30	
	Kitchen (cooking)	20	15	
Offices	Office space	7	20	
	Reception areas	60	15	
	Conference rooms	50	20	
Public Spaces	Smoking lounge	70	60	
	Elevators			1.00
Retail Stores, Sales Floors, Showroom Floors	Basement and street	30		0.30
	Upper floors	20		0.20
	Malls and arcades	20		0.20
	Smoking lounge	70	60	
Sports and Amusement	Spectator areas	150	15	
	Game rooms	70	25	
	Playing floors	30	20	
	Ballrooms and discos	100	25	
Theaters	Lobbies	150	20	
	Auditorium	150	15	
Education	Classroom	50	15	
	Music rooms	50	15	
	Libraries	20	15	
	Auditoriums	150	15	
Hotels, Motels, Resorts, Dormitories	Bedrooms			30 cfm/room
	Living rooms			30 cfm/room
	Lobbies	30	15	
	Conference rooms	50	20	
	Assembly rooms	120	15	

SOURCE: ASHRAE Standard 62-1989, Ventilation for Acceptable Air Quality

Water Chillers

Water chillers are frequently found in large building air conditioning systems because of the superior performance they offer. A water chiller must be maintained in proper working condition to perform its function of removing the heat from the building. Chilled water supply temperatures should operate in the range of 45°F or colder in order to provide proper moisture removal during humid weather. Piping should be insulated to prevent condensation.

Other than thermal comfort, IAQ concerns associated with water chillers involve potential release of the working fluids from the chiller system. The rupture disk (safety release) of the system should be piped to the outdoors, and refrigerant leaks should be located and repaired. Waste oils and spent refrigerant should be disposed of properly.

ASHRAE STANDARDS AND GUIDELINES

Standard 62-1989, "Ventilation for Acceptable Air Quality"

ASHRAE 62-1989 is intended to assist professionals in the proper design of ventilation systems for buildings. The standard presents two procedures for ventilation design, a "Ventilation Rate" procedure and an "Air Quality" procedure.

With the Ventilation Rate procedure, acceptable air quality is achieved by specifying a given quantity and quality of outdoor air based upon occupant density and space usage. Examples of the tables listing the prescriptive amounts of outdoor air for the Ventilation Rate procedure are presented at the end of this section.

The Air Quality procedure is a performance specification that allows acceptable air quality to be achieved within a space by controlling for known and specifiable contaminants. This procedure is seldom used because source strength is usually not known.

Whichever procedure is utilized in the design, the standard states that the design criteria and assumptions shall be documented and made available to those responsible for the operation and maintenance of the system.

Important features of ASHRAE 62-1989 include:

- a definition of acceptable air quality
- a discussion of ventilation effectiveness
- the recommendation of the use of source control through isolation and local exhaust of contaminants
- recommendations for the use of heat recovery ventilation
- a guideline for allowable carbon dioxide levels
- appendices listing suggested possible guidelines for common indoor pollutants

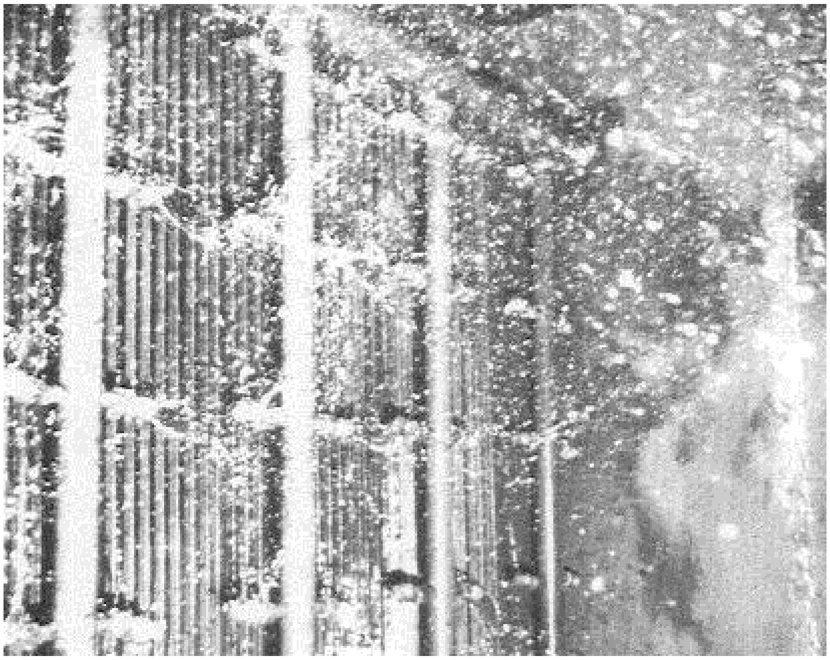
Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy"

ASHRAE 55-1981 covers several environmental parameters including: temperature, radiation, humidity, and air movement.

The standard specifies thermal environmental conditions for the comfort of healthy people in normal indoor environments for winter and summer conditions. It also attempts to introduce limits on the temperature variations within a space. In addition to specifications for temperature and humidity, guidelines are given for air movement, temperature cycling, temperature drift, vertical temperature difference, radiant asymmetry, and floor temperatures. Adjustment factors are described for various activity levels of the occupants, and different clothing levels.

Important features of this standard include:

- a definition of acceptable thermal comfort



This air washer is used to remove particles and water-soluble gaseous contaminants and may also control temperature and humidity in the airstream. Such systems are subject to severe bacterial contamination.

- a discussion of the additional environmental parameters that must be considered
- recommendations for summer and winter comfort zones for both temperature and relative humidity
- a guideline for making adjustment for activity levels
- guidelines for making measurements

It should be noted that space temperatures above 76°F but within the summer comfort envelope have nevertheless been associated with IAQ complaints in offices.

Note: As of summer 1991, a revised Standard 55 was nearly ready.

Standard 52-76, "Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter"

This standard is intended to assist professionals in the evaluation of air cleaning systems for particle removal. Two test methods are described: the weight arrestance test and the atmospheric dust spot test. The standard discusses differences in results from the weight arrestance test and the atmospheric dust spot test. The atmospheric dust spot test is the test used to determine the "efficiency " of an air cleaner. The values obtained with these two tests are not comparable. For example, a filter with a weight arrestance of 90% may have an efficiency by the atmospheric dust spot test below 40%.

The weight arrestance test is generally used to evaluate low efficiency filters designed to remove the largest and heaviest particles; these filters are commonly used in residential furnaces and/or air-conditioning systems or as upstream filters for other air cleaning devices. For the test, a standard synthetic dust is fed into the air cleaner and the proportion (by weight) of the dust trapped on the filter is determined. Because the particles in the standard dust are relatively large, the weight arrestance test is of limited value in assessing the removal of smaller, respirable-size particles from indoor air.

The atmospheric dust spot test is usually used to rate medium efficiency air cleaners. The removal rate is based on the cleaner's ability to reduce soiling of a clean paper target, an ability dependent on the cleaner removing very fine particles from the air. However, it should be noted that this test addresses the overall efficiency of removal of a complex mixture of dust, and that removal efficiencies for different size particles may vary widely. Recent studies by EPA, comparing ASHRAE ratings to filter efficiencies for particles by size, have shown that efficiencies for particles in the size range of 0.1 to 1 microgram are much lower than the ASHRAE rating.

Important features of this ASHRAE standard include:

- definitions of arrestance and efficiency
- establishment of a uniform comparative testing procedure for evaluating the performance of air cleaning devices used in ventilation systems

- establishment of a uniform reporting method for performance
- methods for evaluating resistance to airflow and dust-holding capacity

No comparable guidelines or standards are currently available for use in assessing the ability of air cleaners to remove gaseous pollutants or radon and its progeny.

Guideline 1-1989, "Guideline for the Commissioning of HVAC Systems"

This guideline is intended to assist professionals by providing procedures and methods for documenting and verifying the performance of HVAC systems so that they operate in conformity with the design intent. The guideline presents a format for documenting the occupancy requirements, design assumptions, and the design intent for the HVAC system. It provides a format for testing the system for acceptance by the owner. In addition, the guideline addresses adjustments of the system to meet actual occupancy needs within the capacity of the system when changes in building use are made and recommissioning is warranted.

Important features of this guideline include:

- definition of the commissioning process
- discussion of the process involved in a proper commissioning procedure
- sample specification and forms for logging information
- recommendation for the implementation of corrective measures as warranted
- guideline for operator training
- guidelines for periodic maintenance and recommissioning as needed

Appendix C:
Moisture, Mold and Mildew

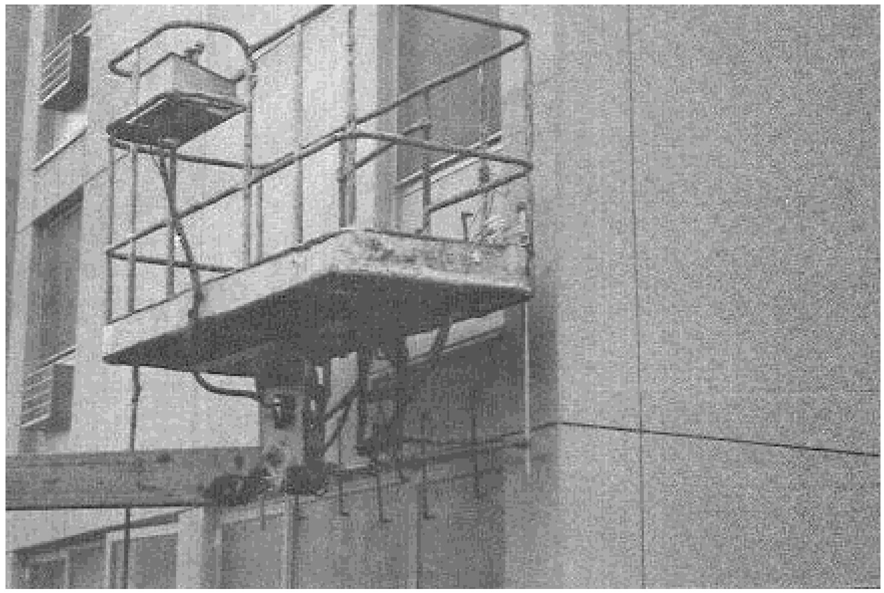
Molds and mildew are fungi that grow on the surfaces of objects, within pores, and in deteriorated materials. They can cause discoloration and odor problems, deteriorate building materials, and lead to allergic reactions in susceptible individuals, as well as other health problems.

The following conditions are necessary for mold growth to occur on surfaces:

- temperature range above 40°F and below 100°F
- mold spores
- nutrient base (most surfaces contain nutrients)
- moisture

Human comfort constraints limit the use of temperature control. Spores are almost always present in outdoor and indoor air, and almost all commonly used construction materials and furnishings can provide nutrients to support mold growth. Dirt on surfaces provides additional nutrients. Cleaning and disinfecting with non-polluting cleaners and antimicrobial agents provides protection against mold growth. Other sections of this document have discussed the importance of building maintenance and proper sanitation in preventing IAQ problems. However, it is virtually impossible to eliminate all nutrients. Moisture control is thus an important strategy for reducing mold growth.

Mold growth does not require the presence of standing water; it can occur when high relative humidity or the hygroscopic properties (the tendency to absorb and retain moisture) of building surfaces allow sufficient moisture to accumulate. Relative humidity and the factors that govern it are often misunderstood. This appendix is intended to give building managers an understanding of the factors that govern relative humidity, and to describe common moisture problems and their solutions.

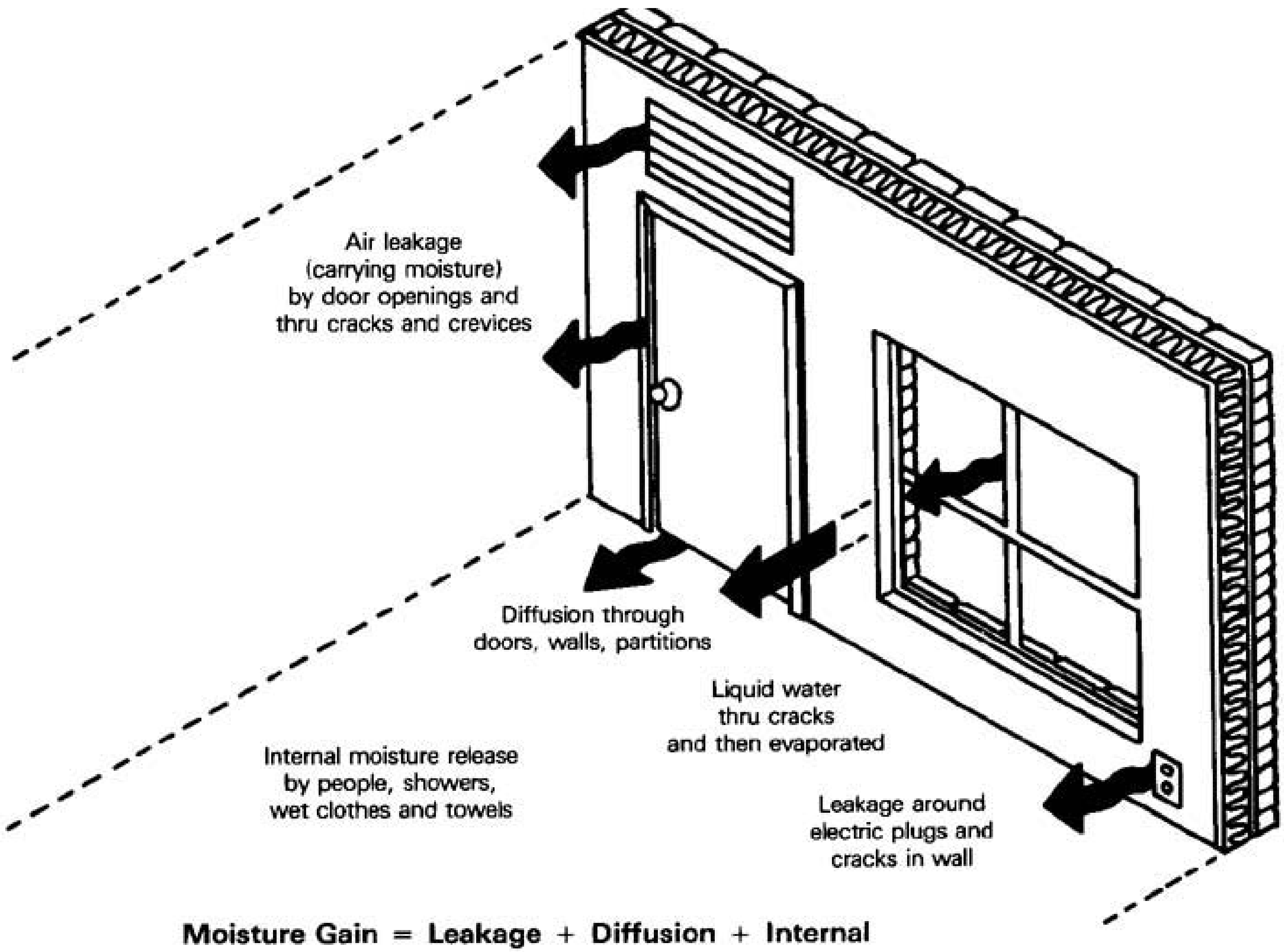


There were complaints of visible water damage and musty odors in this senior citizen housing complex. Investigators confirmed that the problem was rain entry by using an array of hoses to spray the walls with water, while operating the building under negative pressure. The test showed that rain was entering at the joints of the exterior cladding, rather than at cracks around windows.

BACKGROUND ON RELATIVE HUMIDITY, VAPOR PRESSURE, AND CONDENSATION

Water enters buildings both as a liquid and as a gas (water vapor). Water, in its liquid form, is introduced intentionally in bathrooms, kitchens, and laundries and accidentally by way of leaks and spills. Some of that water evaporates and joins the water vapor that is exhaled by building occupants as they breathe or that is introduced by humidifiers. Water vapor also moves in and out of the building as part of the air that is mechanically introduced or that infiltrates and exfiltrates through openings in the building shell. A

FIGURE C-1: Moisture Gain in a Building



Courtesy of Dean Wallace Shakun, Clayton State College, Morrow, GA

lesser amount of water vapor diffuses into and out of the building through the building materials themselves. Figure C-1 illustrates locations of moisture entry.

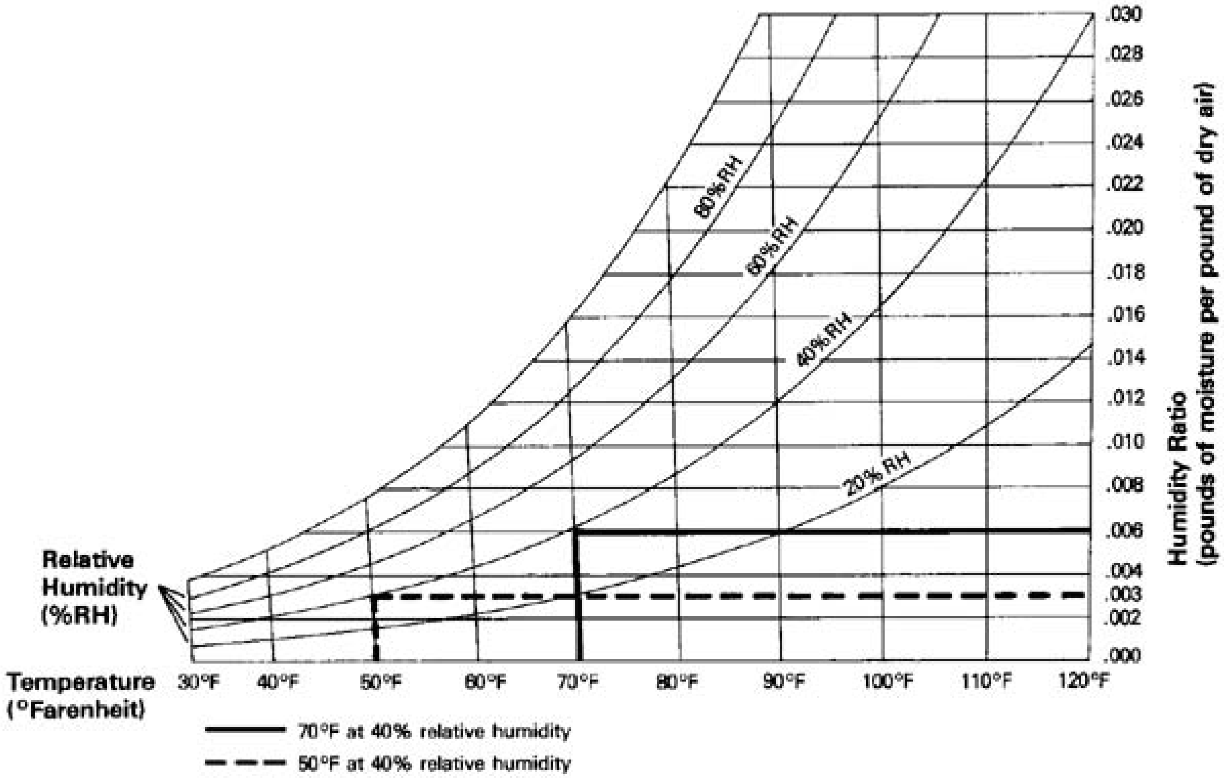
The ability of air to hold water vapor decreases as the air temperature is lowered. If a unit of air contains half of the water vapor it can hold, it is said to be at 50% relative humidity (RH). As the air cools, the relative humidity increases. If the air contains all of the water vapor it can hold, it is at 100% RH, and the water vapor condenses, changing from a gas to a liquid. It is possible to reach 100% RH without changing the amount of water vapor in the air (its "vapor pressure" or "absolute humidity"); All that is required is for the air temperature to drop to the "dew point."

Relative humidity and temperature often vary within a room, while the absolute humidity in the room air can usually be assumed to be uniform. Therefore, if one side of the room is warm and the other side cool, the cool side of the room has a higher RH than the warm side.

The highest RH in a room is always next to the coldest surface. This is referred as the "first condensing surface," as it will

FIGURE C-2: Relationship of Temperature, Relative Humidity, and Moisture in the Air

A relative humidity reading taken in a room will only give an accurate indication of the actual amount of moisture present if a temperature reading is taken at the same time. The chart below shows that air at 70°F and 40% RH contains approximately 0.006 pounds of moisture per pound of dry air (as indicated by the bold line), while air that is at 50°F and 40% RH contains approximately 0.003 pounds of moisture per pound of dry air (as indicated by the dashed line). Although both are at 40% RH, the 70°F air contains roughly twice as much moisture as the 50°F air.

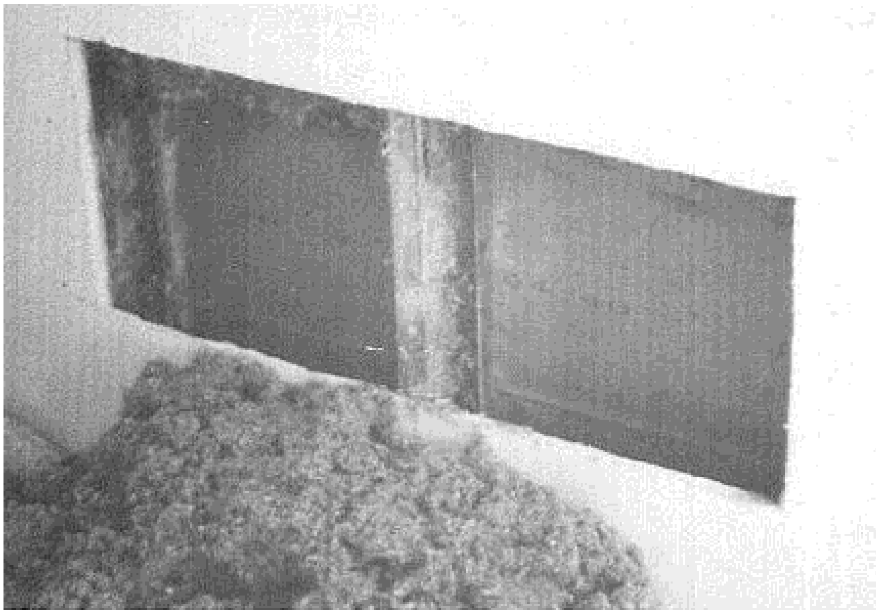


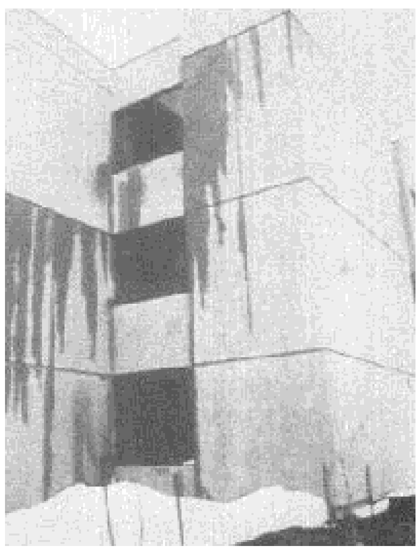
SOURCE: Adapted from Psychometric Chart from ASHRAE Fundamentals, 1981

be the location where condensation first occurs, if the relative humidity at the surface reaches 100%. It is important to understand this when trying to understand why mold is growing on one patch of wall or only along the wall-ceiling joint. It is likely that the surface of the wall is cooler than the room air because there is a void in the insulation or because wind is blowing through cracks in the exterior of the building.

TAKING STEPS TO REDUCE MOISTURE

Mold and mildew growth can be reduced where relative humidities near surfaces can be maintained below the dew point. This can be accomplished by reducing the moisture content (vapor pressure) of the air, increasing air movement at the surface, or increasing the air temperature (either the general space temperature or the temperature at building surfaces).





***Above:** In this building, mold and mildew spots appeared on drywall joints on the interior walls. When the wall was cut open, mold growth was visible in the wall cavity and the structural steel showed corrosion. The problem was caused by construction moisture trapped between the interior finish and the exterior sheathing. The solution was to modify the exterior wall so that moisture could vent to the outdoors. **Below:** This is visual evidence of air movement through the building shell. The water vapor in the warm, humid indoor air has condensed and frozen on the exterior wall.*

Either surface temperature or vapor pressure can be the dominant factor in causing a mold problem. A surface temperature-related mold problem may not respond very well to increasing ventilation, whereas a vapor pressure-related mold problem may not respond well to increasing temperatures. Understanding which factor dominates will help in selecting an effective control strategy.

Consider an old, leaky, poorly insulated building. It is in a heating climate and shows evidence of mold and mildew. Since the building is leaky, its high natural air exchange rate dilutes interior airborne moisture levels, maintaining a low absolute humidity during the heating season. Providing mechanical ventilation in this building in an attempt to control interior mold and mildew probably will not be effective in this case. Increasing surface temperatures by insulating the exterior walls, and thereby reducing relative humidities next to the wall surfaces, would be a better strategy to control mold and mildew.

Reduction of **surface temperature-dominated mold and mildew** is best accomplished by increasing the surface temperature through either or both of the following approaches:

- Increase the temperature of the air near room surfaces either by raising the thermostat setting or by improving air circulation so that supply air is more effective at heating the room surface.
- Decrease the heat loss from room surfaces either by adding insulation or by closing cracks in the exterior wall to prevent wind-washing (air that enters a wall at one exterior location and exits another exterior location without penetrating into the building).

Vapor pressure-dominated mold and mildew can be reduced by one or more of the following strategies:

- source control (e.g., direct venting of moisture-generating activities such as showers) to the exterior
- dilution of moisture-laden indoor air with outdoor air that is at a lower absolute humidity
- dehumidification

Note that dilution is only useful as a control strategy during heating periods, when cold outdoor air tends to contain less moisture. During cooling periods, outdoor air often contains as much moisture as indoor air.

IDENTIFYING AND CORRECTING COMMON PROBLEMS FROM MOLD AND MILDEW

Exterior Corners

Exterior corners are common locations for mold and mildew growth in heating climates, and in poorly insulated buildings in cooling climates. They tend to be closer to the outdoor temperature than other parts of the building surface for one or more of the following reasons:

- poor air circulation (interior)
- wind-washing (exterior)
- low insulation levels
- greater surface area of heat loss

Sometimes mold and mildew growth can be reduced by removing obstructions to airflow (e.g., rearranging furniture). Buildings with forced air heating systems and/or room ceiling fans tend to have fewer mold and mildew problems than buildings with less air movement, other factors being equal.

"Set Back" Thermostats

Set back thermostats are commonly used to reduce energy consumption during the heating season. Mold and mildew growth can occur when building temperatures are lowered during unoccupied periods. (Maintaining a room at too low a temperature can have the same effect as a set back thermostat.) Mold and mildew can often be controlled in heating climate locations by increasing interior temperatures during heating periods. Unfortunately, this also increases energy consumption and reduces relative humidity in the breathing zone, which can create discomfort.

Air Conditioned Spaces

The problems of mold and mildew can be as extensive in cooling climates as in heating climates. The same principles apply: either surfaces are too cold, moisture levels are too high, or both.

A common example of mold growth in cooling climates can be found in rooms where conditioned "cold" air blows against the interior surface of an exterior wall. This condition, which may be due to poor duct design, diffuser location, or diffuser performance, creates a cold spot at the interior finish surfaces. A mold problem can occur within the wall cavity as outdoor air comes in contact with the cavity side of the cooled interior surface. It is a particular problem in rooms decorated with low

HOW TO IDENTIFY THE CAUSE OF A MOLD AND MILDEW PROBLEM

Mold and mildew are commonly found on the exterior wall surfaces of corner rooms in heating climate locations. An exposed corner room is likely to be significantly colder than adjoining rooms, so that it has a higher relative humidity (RH) than other rooms at the same water vapor pressure. If mold and mildew growth are found in a corner room, then relative humidities next to the room surfaces are above 70%. However, is the RH above 70% at the surfaces because the room is too cold or because there is too much moisture present (high water vapor pressure)?

The amount of moisture in the room can be estimated by measuring both temperature and RH at the same location and at the same time. Suppose there are two cases. In the first case, assume that the RH is 30% and the temperature is 70°F in the middle of the room. The low RH at that temperature indicates that the water vapor pressure (or absolute humidity) is low. The high surface RH is probably due to room surfaces that are "too cold." Temperature is the dominating factor, and control strategies should involve increasing the temperature at cold room surfaces.

In the second case, assume that the RH is 50% and the temperature is 70°F in the middle of the room. The higher RH at that temperature indicates that the water vapor pressure is high and there is a relatively large amount of moisture in the air. The high surface RH is probably due to air that is "too moist." Humidity is the dominating factor, and control strategies should involve decreasing the moisture content of the indoor air.

maintenance interior finishes (e.g., impermeable wall coverings such as vinyl wallpaper) which can trap moisture between the interior finish and the gypsum board. Mold growth can be rampant when these interior finishes are coupled with cold spots and exterior moisture.

Possible solutions for this problem include:

- preventing hot, humid exterior air from contacting the cold interior finish (i.e., controlling the vapor pressure at the surface)
- eliminating the cold spots (i.e., elevating the temperature of the surface) by relocating ducts and diffusers
- ensuring that vapor barriers, facing sealants, and insulation are properly specified, installed, and maintained
- increasing the room temperature to avoid overcooling

In this case, increasing temperature decreases energy consumption, though it could cause comfort problems.

Thermal Bridges

Localized cooling of surfaces commonly occurs as a result of "thermal bridges," elements of the building structure that are highly conductive of heat (e.g., steel studs in exterior frame walls, uninsulated window lintels, and the edges of concrete floor slabs). Dust particles sometimes mark the locations of thermal bridges, because dust tends to adhere to cold spots.

The use of insulating sheathings significantly reduces the impact of thermal bridges in building envelopes.

Windows

In winter, windows are typically the coldest surfaces in a room. The interior surface of a window is often the first condensing surface in a room.

Condensation on window surfaces has historically been controlled by using storm windows or "insulated glass" (e.g., double-glazed windows or selective surface gas-filled windows) to raise interior surface temperatures. The advent of higher performance glazing systems has led to a greater incidence of moisture problems in heating climate building enclosures, because the buildings can now be operated at higher interior vapor pressures (moisture levels) without visible surface condensation on windows. In older building enclosures with less advanced glazing systems, visible condensation on the windows often alerted occupants to the need for ventilation to flush out interior moisture (so they opened the windows).

Concealed Condensation

The use of thermal insulation in wall cavities increases interior surface temperatures in heating climates, reducing the likelihood of interior surface mold, mildew and condensation. However, the use of thermal insulation also reduces the heat loss from the conditioned space into the wall cavities, decreasing the temperature in the wall cavities and therefore increasing the likelihood of concealed condensation. The first condensing surface in a wall cavity in a heating climate is typically the inner surface of the exterior sheathing, the "back side" of plywood or fiberboard. As the insulation value is increased in the wall cavities, so does the potential for hidden condensation.

Concealed condensation can be controlled by either or both of the following strategies:

- Reducing the entry of moisture into the wall cavities (e.g., by controlling infiltration and/or exfiltration of moisture-laden air)
- Elevating the temperature of the first condensing surface. In heating climate locations, this change can be made by installing exterior insulation (assuming that no significant wind-washing is occurring). In cooling climate locations, this change an be made by installing insulating sheathing to the interior of the wall framing and between the wall framing and the interior gypsum board.

Appendix D: Asbestos

"Asbestos" describes six naturally occurring fibrous minerals found in certain types of rock formations. When mined and processed, asbestos is typically separated into very thin fibers that are normally invisible to the naked eye. They may remain in the air for many hours if released from asbestos-containing material (ACM) and may be inhaled during this time. Three specific diseases — asbestosis (a fibrous scarring of the lungs), lung cancer, and mesothelioma (a cancer of the lining of the chest or abdominal cavity) — have been linked to asbestos exposure. It may be 20 years or more after exposure before symptoms of these diseases appear; however, high levels of exposure can result in respiratory diseases in a shorter period of time.

Most of the health problems resulting from asbestos exposure have been experienced by workers whose jobs exposed them to asbestos in the air over a prolonged period without the worker protection that is now required. Asbestos fibers can be found nearly everywhere in our environment (usually at very low levels). While the risk to occupants is likely to be small, health concerns remain, particularly for the custodial and maintenance workers in a building. Their jobs are likely to bring them into proximity to ACM and may sometimes require them to disturb the ACM in the performance of maintenance activities.

EPA estimates that "friable" (easily crumbled) ACM can be found in an estimated 700,000 public and commercial buildings. About 500,000 of those buildings are believed to contain at least some damaged asbestos. Significantly damaged ACM is found primarily in building areas not generally accessible to the public, such as boiler and mechanical rooms, where asbestos exposures generally would be limited to service and maintenance workers. However, if friable ACM is present in air plenums, it can be distributed throughout the building, thereby possibly exposing building occupants.

When is asbestos a problem? **Intact and undisturbed asbestos materials do not pose a health risk.** The mere presence of asbestos in a building does not mean that the health of building occupants is endangered. ACM which is in good condition, and is not damaged or disturbed, is not likely to release asbestos fibers into the air. When ACM is properly managed, release of asbestos fibers into the air is reduced, and the risk of asbestos-related disease is thereby correspondingly reduced.

There are a number of guidelines and regulations that govern asbestos exposure. Occupational standards for preventing asbestos-related diseases are recommended by NIOSH and promulgated by OSHA. NIOSH guidance contain Recommended Exposure Limits (RELs) and OSHA standards set Permissible Exposure Limits (PELs). The standards also contain many other measures, such as surveillance, medical screening, analytical methods, and methods of control. OSHA regulations and the EPA Worker Protection Rule also provide guidance on day-to-day activities that may bring workers in contact with ACM. EPA National Emission Standards for Hazardous Air Pollutants (NESHAP) define acceptable practices for renovation and demolition activities that involve asbestos-containing materials. In addition, many States have set exposure standards and other regulations concerning asbestos.

EPA and NIOSH recommend a practical approach that protects public health by emphasizing that ACM in buildings should be identified and appropriately managed, and that those workers who might disturb it should be properly trained and protected.

EPA AND NIOSH POSITIONS ON ASBESTOS

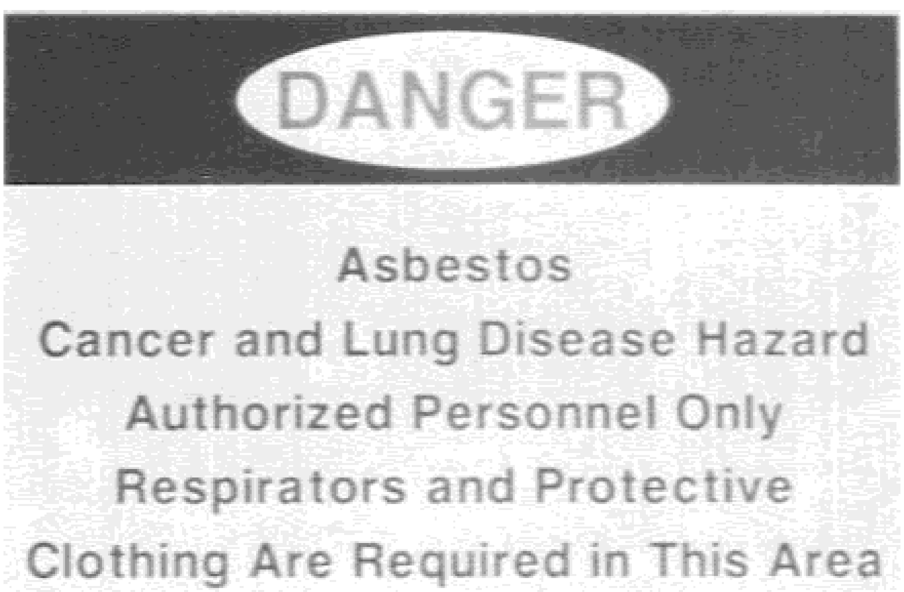
In an effort to calm unwarranted fears that a number of people seem to have about the mere presence of asbestos in their buildings and to discourage the decisions by some building owners to remove all ACM regardless of its condition, the EPA Administrator issued an *Advisory to the Public on Asbestos in Buildings* in 1991. This advisory summarized EPA's policies for asbestos control in the presentation of the following "five facts":

- Although asbestos is hazardous, the risk of asbestos-related disease depends upon exposure to airborne asbestos fibers.
- Based upon available data, the average airborne asbestos levels in buildings seem to be very low. Accordingly, the health risk to most building occupants also appears to be very low.
- Removal is often not a building owner's best course of action to reduce asbestos exposure. In fact, an improper removal can create a dangerous situation where none previously existed.
- EPA only requires asbestos removal in order to prevent significant public exposure to airborne asbestos fibers during building demolition or renovation activities.
- EPA does recommend a pro-active, in-place management program whenever asbestos-containing material is discovered.

NIOSH's position on asbestos exposure has been expressed in NIOSH policy statements and internal reports and at OSHA public hearings:

- NIOSH recommends the goal of eliminating asbestos exposure in the workplace. Where exposures cannot be eliminated, exposures should be limited to the lowest concentration possible.
- NIOSH contends that there is no safe airborne fiber concentration for asbestos. NIOSH therefore believes that any detectable concentration of asbestos in the workplace warrants further evaluation and, if necessary, the implementation of measures to reduce exposures.
- NIOSH contends that there is no scientific basis to support differentiating health risks between types of asbestos fibers for regulatory purposes.

Copies of the EPA and NIOSH policy statements and public advisories are available, respectively, from those agencies. See the last section in this appendix and the *Resources* section for information on how to obtain them.



OSHA requires that signs be posted around areas where work is being done that involves damaged asbestos-containing materials. These signs must communicate specific types of information.

PROGRAMS FOR MANAGING ASBESTOS IN-PLACE

In some cases, an asbestos operations and maintenance program is more appropriate than other asbestos control strategies, including removal. Proper asbestos management is neither to rip it all out in a panic nor to ignore the problem under the false presumption that asbestos is "risk free." Health concerns remain, particularly for custodial and maintenance workers.

In-place management does not mean "do nothing." It means having a program to ensure that the day-to-day management of the building is carried out in a manner that minimizes release of asbestos fibers into the air, and that ensures that when asbestos fibers are released, either accidentally or intentionally, proper control and clean-up procedures are implemented. Such a program may be all that is necessary to control the release of asbestos fibers until the asbestos-containing material in a building is scheduled to be disturbed by renovation or demolition activities.

The first responsibility of a building owner or manager is to identify asbestos-containing materials, through a building-wide inventory or on a case-by-case basis, before suspect materials are disturbed by renovations or other actions. The Asbestos Hazard Emergency Response Act (AHERA) program requires that in schools an inventory of asbestos materials be done by properly accredited individuals. Starting in late 1991 or 1992, there will also be a requirement that if an inventory of asbestos materials is done in public and commercial buildings, the inventory must be done by properly accredited individuals. In public and commercial buildings facing major renovations or demolition, inspections for the presence of ACM are required, according to the 1990 revision of the EPA Asbestos NESHAP. A carefully designed air monitoring program can be used as an adjunct to visual and physical evaluations of the asbestos-containing materials.

After the material is identified, the building management and staff can then institute controls to ensure that the day-to-day management of the building is carried out in a manner that prevents or minimizes the release of asbestos fibers into the air. These controls will ensure that when asbestos fibers are released, either accidentally or intentionally, proper management and clean-up procedures are implemented.

Another concern of EPA, NIOSH, and other Federal, State, and local agencies that are concerned with asbestos and public health is to ensure proper worker training and protection. In the course of their daily activities, maintenance and service workers in buildings may disturb materials and thereby elevate asbestos fiber levels and asbestos exposure, especially for themselves, if they are not properly trained and protected. For these persons, risk may be significantly higher than for other building occupants. Proper worker training and protection, as part of an active in-place management program, can reduce any unnecessary asbestos exposure for these workers and others. AHERA requires this training for school employees whose job activities may result in asbestos disturbances.

In addition to the steps outlined above, an in-place management program will usually include notification to workers and occupants of the existence of asbestos in their building, periodic surveillance of the material, and proper recordkeeping. EPA requires all of these activities for schools and strongly recommends that other building owners also establish comprehensive asbestos management programs. Without such programs, asbestos materials could be damaged or could deteriorate, which might result in elevated levels of airborne asbestos fibers. While the management costs of all the above activities will depend upon the amount, condition, and location of the materials, such a program need not be expensive.

WHERE TO GO FOR ADDITIONAL INFORMATION

For guidance on asbestos, building owners and managers are urged to become familiar with two EPA documents: *Managing Asbestos in Place* (published in 1990 and also known as the "Green Book") and *Guidance for Controlling Asbestos-Containing Materials in Buildings* (published in 1985 and also known as the "Purple Book").

To obtain copies of the guidance publications and other materials mentioned above, or to get additional information on technical issues, call or write:

Environmental Assistance Division
Office of Toxic Substances
U.S. EPA (TS-799)
401 M Street SW
Washington, DC 20460
Telephone (TSCA Information Hotline): 202-554-1404

National Institute for Occupational Safety and Health
Technical Information Branch
4676 Columbia Parkway
Cincinnati, OH 45226
Telephone: 1-800-35-NIOSH or 1-800-356-4674

Contact State air pollution control or health agencies for information on pertinent State activities and regulations. To find an asbestos contact in State agencies, consult the EPA Directory of State Indoor Air Contacts. For a more complete listing of publications concerning asbestos, refer to *Appendix G*.

Appendix E: Radon

Radon is a radioactive gas produced by the decay of radium. It occurs naturally in almost all soil and rock. Radon migrates through the soil and groundwater and can enter buildings through cracks or other openings in their foundations. Radon's decay products can cause lung cancer, and radon is second only to smoking as a cause of lung cancer in America.

Based on early data, the EPA concentrated its radon reduction efforts on one- and two- family homes. Citing results from a radon survey conducted jointly with 25 States, the EPA and the Surgeon General's office issued a National Health Advisory that called for testing most homes for the presence of radon. Extensive research and case studies in the field have demonstrated practical remediation methods that typically reduce the indoor radon concentrations below 4 pCi/L, the current EPA action level for all occupied buildings.

Now that EPA technical guidance is being successfully used to reduce human health risk in homes, the EPA is emphasizing the development of radon measurement, mitigation, and prevention techniques for schools and large buildings. Preliminary data from a nationwide survey of Federal buildings indicates that radon will probably not be as widespread a problem in large buildings as it is in homes. One of the major factors for this difference is that multi-story buildings have proportionally less space in direct contact with the earth when compared to homes.

Some of the control technologies utilized for homes are being studied for their appropriateness to other building types, including schools and large buildings. In addition, new methods and technologies are being developed to ensure a practical and cost-effective reduction of radon in these buildings. As a result, published documents on guidance and protocols for measurement and remediation of radon in large buildings are not currently available.

This publication provides an overview of radon issues, and should be used only as background information. For more information, refer to other sources of information that are specific to radon in indoor air.

BUILDING MEASUREMENT, DIAGNOSIS, AND REMEDIATION

Protocols specific to the measurement of radon and radon progeny in large buildings are tentatively scheduled to be published by EPA in early 1992. These large building measurement protocols can assist skilled building owner or facility personnel in making initial screening tests for the presence of radon. A new protocol specific to large buildings is necessary due to the major differences in building dynamics, HVAC systems, and occupancy patterns between large buildings and homes, and how these impact radon.

As part of its effort to develop widespread State and private sector capabilities, the EPA established a voluntary proficiency program (Radon Measurement Proficiency Program) for radon laboratories and commercial measurement firms. *A State Proficiency Report* (EPA 520/1-91-014), which gives information on specific radon measurement firms in your area, can be obtained from your State radon office or from your EPA Regional Office.

Three elements must be present for radon to be a problem: a radon source, a pathway that allows radon to enter the building, and a driving force that causes the radon to flow through the pathway and into the building. Preventing radon from entering the building is always desirable compared with mitigation after radon has entered. The reduction of pathways and driving forces are therefore usually the focus of attention during diagnostic and remediation efforts.

Due to the diversity and complexity of large buildings, and because the research and development of appropriate radon remediation technologies for these structures are in the early phases, generalized building diagnostic and remediation methodologies are not yet available. For assistance, please contact the appropriate organizations on the following list or a professional engineering firm or mitigation company with experience in this matter.

WHERE TO GO FOR ADDITIONAL INFORMATION

State Radon Offices
There are several ways to get the name of a contact person in your State radon office or information about that office. You can call the radon contact in the EPA Regional Office for your state or you can order the *Directory of State Indoor Air Contacts* from the EPA Public Information Center. (See list of IAQ and radon contacts and list of EPA publications in *Appendix G*.)

Regional Radon Training Centers
As part of its effort to develop State and private sector capabilities for radon reduction, the EPA has coordinated the formation of four Regional Radon Training Centers (RRTCs). The RRTCs provide a range of radon training and proficiency examination courses to the public for a fee.

Eastern Regional Radon Training Center
Rutgers, The State University
Livingston Campus, Building 4087
New Brunswick, NJ 08903-0231
908-932-2582

Mid-West Universities Radon Consortium
University of Minnesota
1985 Buford Avenue (240)
St. Paul, MN 55108-6136
612-624-8747

Western Regional Radon Training Center
Guggenheim Hall
Colorado State University
Fort Collins, CO 80523
1-800-462-7459/303-491-7742

Southern Regional Radon Training Center
Auburn University
Housing Research Center
Harbert Engineering Center
Auburn University, AL 36849-5337
205-844-6261

EPA Regional Offices
If you want additional information from EPA regarding radon, start with the EPA Regional Offices. Telephone numbers for radon information contacts are given in the list of EPA Regional Offices in *Appendix G* of this publication.

EPA Radon Division
If information is unavailable from the above sources, please contact the EPA Radon Division at:

Radon Division (ANR-464)
U.S. EPA
401 M Street, SW
Washington, DC 20460
202-260-9605

Appendix F: Glossary and Acronyms

ACGIH — American Conference of Governmental Industrial Hygienists.

ASHRAE — American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ASTM — American Society for Testing and Materials.

Air Cleaning — An IAQ control strategy to remove various airborne particulates and/or gases from the air. The three types of air cleaning most commonly used are particulate filtration, electrostatic precipitation, and gas sorption.

Air Exchange Rate — Used in two ways: 1) the number of times that the outdoor air replaces the volume of air in a building per unit time, typically expressed as air changes per hour; 2) the number of times that the ventilation system replaces the air within a room or area within the building.

Antimicrobial — Agent that kills microbial growth. See "disinfectant," "sanitizer", and "sterilizer."

BRI — See "Building-Related Illness."

Biological Contaminants — Agents derived from or that are living organisms (e.g., viruses, bacteria, fungi, and mammal and bird antigens) that can be inhaled and can cause many types of health effects including allergic reactions, respiratory disorders, hypersensitivity diseases, and infectious diseases. Also referred to as "microbiologicals" or "microbials."

Breathing Zone — Area of a room in which occupants breathe as they stand, sit, or lie down.

Building Envelope — Elements of the building, including all external building materials, windows, and walls, that enclose the internal space.

Building-Related Illness — Diagnosable illness whose symptoms can be identified and whose cause can be directly attributed to airborne building pollutants (e.g., Legionnaire's disease, hypersensitivity pneumonitis).

CFM — Cubic feet per minute.

CO — Carbon monoxide.

CO_2 — Carbon dioxide.

Ceiling Plenum — Space below the flooring and above the suspended ceiling that accommodates the mechanical and electrical equipment and that is used as part of the air distribution system. The space is kept under negative pressure.

Commissioning — Start-up of a building that includes testing and adjusting HVAC, electrical, plumbing, and other systems to assure proper functioning and adherence to design criteria. Commissioning also includes the instruction of building representatives in the use of the building systems.

Conditioned Air — Air that has been heated, cooled, humidified, or dehumidified to maintain an interior space within the "comfort zone." (Sometimes referred to as "tempered" air.)

Constant Air Volume Systems — Air handling system that provides a constant air flow while varying the temperature to meet heating and cooling needs.

Dampers — Controls that vary airflow through an air outlet, inlet, or duct. A damper position may be immovable, manually adjustable, or part of an automated control system.

Diffusers and Grilles — Components of the ventilation system that distribute and diffuse air to promote air circulation in the occupied space. Diffusers supply air and grilles return air.

Disinfectants — One of three groups of antimicrobials registered by EPA for public health uses. EPA considers an antimicrobial to be a disinfectant when it destroys or irreversibly inactivates infectious or other undesirable organisms, but not necessarily their spores. EPA registers three types of disinfectant products based upon submitted efficacy data: limited, general or broad spectrum, and hospital disinfectant.

EPA — United States Environmental Protection Agency.

ETS — Environmental tobacco smoke.

Environmental Agents — Conditions other than indoor air contaminants that cause stress, comfort, and/or health problems (e.g., humidity extremes, drafts, lack of air circulation, noise, and overcrowding).

Ergonomics — Applied science that investigates the impact of people's physical environment on their health and comfort (e.g., determining the proper chair height for computer operators).

Exhaust Ventilation — Mechanical removal of air from a portion of a building (e.g., piece of equipment, room, or general area).

Gas Sorption — Devices used to reduce levels of airborne gaseous compounds by passing the air through materials that extract the gases. The performance of solid sorbents is dependent on the airflow rate, concentration of the pollutants, presence of other gases or vapors, and other factors.

HEPA — High efficiency particulate arrestance (filters).

HVAC — Heating, ventilation, and air-conditioning system.

Hypersensitivity Diseases — Diseases characterized by allergic responses to animal antigens. The hypersensitivity diseases most clearly associated with indoor air quality are asthma, rhinitis, and hypersensitivity pneumonitis. Hypersensitivity pneumonitis is a rare but serious disease that involves progressive lung damage as long as there is exposure to the causative agent.

IAQ — Indoor air quality.

IPM — Integrated pest management.

Indicator Compounds — Chemical compounds, such as carbon dioxide, whose presence at certain concentrations may be used to estimate certain building conditions (e.g., airflow, presence of sources).

MCS — See "Multiple Chemical Sensitivity."

MSDS — Material Safety Data Sheet.

Make-up Air — Air brought into a building from the outdoors through the ventilation system that has not been previously circulated through the system.

Microbiologicals — See "Biological Contaminants."

Multiple Chemical Sensitivity — A term used by some people to refer to a condition in which a person is considered to be sensitive to a number of chemicals at very low concentrations. There are a number of views about the existence, potential causes, and possible remedial actions regarding this phenomenon.

NIOSH — National Institute for Occupational Safety and Health.

NTIS — National Technical Information Service.

Negative Pressure — Condition that exists when less air is supplied to a space than is exhausted from the space, so the air pressure within that space is less than that in surrounding areas.

OSHA — Occupational Safety and Health Administration.

PELs — Permissible Exposure Limits (standards set by OSHA).

PM — Preventive Maintenance.

Plenum — Air compartment connected to a duct or ducts.

Positive Pressure — Condition that exists when more air is supplied to a space than is exhausted, so the air pressure within that space is greater than that in surrounding areas.

Psychosocial Factors — Psychological, organizational, and personal stressors that could produce symptoms similar to poor indoor air quality.

RELs — Recommended Exposure Limits (recommendations made by NIOSH).

Radiant Heat Transfer — Radiant heat transfer occurs when there is a large difference between the temperatures of two surfaces that are exposed to each other, but are not touching.

Re-entrainment —Situation that occurs when the air being exhausted from a building is immediately brought back into the system through the air intake and other openings in the building envelope.

SBS — See "Sick Building Syndrome."

Sanitizer — One of three groups of antimicrobials registered by EPA for public health uses. EPA considers an antimicrobial to be a sanitizer when it reduces but does not necessarily eliminate all the microorganisms on a treated surface. To be a registered sanitizer, the test results for a product must show a reduction of at least 99.9% in the number of each test microorganism over the parallel control.

Short-circuiting — Situation that occurs when the supply air flows to exhaust registers before entering the breathing zone. To avoid short-circuiting, the supply air must be delivered at a temperature and velocity that results in mixing throughout the space.

Sick Building Syndrome — Term sometimes used to describe situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be spread throughout the building.

Soil Gases — Gases that enter a building from the surrounding ground (e.g., radon, volatile organics, pesticides).

Stack Effect —Pressure-driven airflow produced by convection as heated air rises, creating a positive pressure area at the top of a building and a negative pressure area at the bottom of a building. The stack effect can overpower the mechanical system and disrupt ventilation and circulation in a building.

Static Pressure — Condition that exists when an equal amount of air is supplied to and exhausted from a space. At static pressure, equilibrium has been reached.

Sterilizer — One of three groups of antimicrobials registered by EPA for public health uses. EPA considers an antimicrobial to be a sterilizer when it destroys or eliminates all forms of bacteria, fungi, viruses, and their spores. Because spores are considered the most difficult form of a microorganism to destroy, EPA considers the term sporicide to be synonymous with "sterilizer."

TLVs — Threshold Limit Values (guidelines recommended by ACGIH).

TVOCs — Total volatile organic compounds.

Tracer Gases — Compounds, such a sulfur hexafluoride, which are used to identify suspected pollutant pathways and to quantify ventilation rates. Tracer gases may be detected qualitatively by their odor or quantitatively by air monitoring equipment.

VAV — Variable air volume system.

VOCs — See "Volatile Organic Compounds."

Variable Air Volume System — Air handling system that conditions the air to a constant temperature and varies the outside airflow to ensure thermal comfort.

Ventilation Air — Defined as the total air, which is a combination of the air brought into the system from the outdoors and the air that is being recirculated within the building. Sometimes, however, used in reference only to the air brought into the system from the outdoors.

Volatile Organic Compounds (VOCs) — Compounds that evaporate from the many housekeeping, maintenance, and building products made with organic chemicals. These compounds are released from products that are being used and that are in storage. In sufficient quantities, VOCs can cause eye, nose, and throat irritations, headaches, dizziness, visual disorders, memory impairment; some are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans. At present, not much is known about what health effects occur at the levels of VOCs typically found in public and commercial buildings.

WHO — World Health Organization.

Appendix G: Resources

FEDERAL AGENCIES WITH MAJOR INDOOR AIR RESPONSIBILITY FOR PUBLIC AND COMMERCIAL BUILDINGS

U.S. Environmental Protection Agency

Conducts a non-regulatory indoor air quality program that emphasizes research, information dissemination, technical guidance, and training. Issues regulations and carries out other activities that affect indoor air quality under the laws for pesticides, toxic substances, and drinking water.

Public Information Center
(PM-211B)
401 M Street, SW
Washington, DC 20460
202-382-2080
Distributes indoor air quality publications.

National Pesticides Telecommunications
Network National toll-free number:
1-800-858-PEST
In Texas: 806-743-3091
Provides information on pesticides.

TSCA Hotline Service
202-554-1404
Provides information on asbestos and other toxic substances.

Occupational Safety and Health Administration

Promulgates safety and health standards, facilitates training and consultation, and enforces regulations to ensure that workers are provided with safe and healthful working conditions. (For further information contact OSHA Regional Offices.)

National Institute for Occupational Safety and Health

Conducts research, recommends standards to the U.S. Department of Labor, and conducts training on various issues including indoor air quality to promote safe and healthful workplaces. Undertakes investigations at request of employees, employers, other federal agencies, and state and local agencies to identify and mitigate workplace problems.

Requests for Field Investigations
NIOSH
Hazard Evaluations and Technical
Assistance Branch (R-9)
4676 Columbia Parkway
Cincinnati, OH 45226
513-841-4382

Requests for Information:
1-800-35-NIOSH
or 1-800-356-4674

EPA Regional Offices

Address inquiries to the contacts in the EPA Regional Offices at the following addresses:

(CT,ME,MA,NH,RI,VT)
EPA Region 1
John F. Kennedy Federal Building
Boston, MA 02203
617-565-3232 (indoor air)
617-565-4502 (radon)
617-565-3744 (asbestos)
617-565-3265 (NESHAP)

(NJ,NY,PR,VI)
EPA Region 2
26 Federal Plaza
New York, NY 10278
212-264-4410 (indoor air)
212-264-4410 (radon)
212-264-6671 (asbestos)
212-264-6770 (NESHAP)

(DE,DC,MD,PA,VA,WV)
EPA Region 3
841 Chestnut Building
Philadelphia, PA 19107
215-597-8322 (indoor air)
215-597-4084 (radon)
215-597-3160 (asbestos)
215-597-1970 (NESHAP)

(AL,FL,GA,KY,MS,NC,SC,TN)
EPA Region 4
345 Courtland Street, NE
Atlanta, GA 30365
404-347-2864 (indoor air)
404-347-3907 (radon)
404-347-5014 (asbestos)
404-347-5014 (NESHAP)

(IL,IN,MI,MN,OH,WI)
EPA Region 5
230 South Dearborn Street
Chicago, IL 60604
Region 5 Environmental Hotline:
1-800-572-2515 (IL)
1-800-621-8431 (IN, MI, MN, OH, WI)
312-886-7930 (outside Region 5)

(AR,LA,NM,OK,TX)
EPA Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
214-655-7223 (indoor air)
214-655-7223 (radon)
214-655-7223 (asbestos)
214-655-7223 (NESHAP)

(IA,KS,MO,NE)
EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
913-551-7020 (indoor air)
913-551-7020 (radon)
913-551-7020 (asbestos)
913-551-7020 (NESHAP)

(CO,MT,ND,SD,UT,WY)
EPA Region 8
999 18th Street Suite 500
Denver, CO 80202-2405
303-293-1440 (indoor air)
303-293-0988 (radon)
303-293-1442 (asbestos)
303-294-7611 (NESHAP)

(AZ,CA,HI,NV,AS,GU)
EPA Region 9
75 Hawthorne Street, A-1-1
San Francisco, CA 94105
415-744-1133 (indoor air)
415-744-1045 (radon)
415-744-1136 (asbestos)
415-744-1135 (NESHAP)

(AK,ID,OR,WA)
EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
206-553-2589 (indoor air)
206-553-7299 (radon)
206-553-4762 (asbestos)
206-553-1757 (NESHAP)

OSHA Regional Offices

(CT,ME,MA,NH,RI,VT)
OSHA Region 1
133 Portland Street, 1st Floor
Boston, MA 02114
617-565-7164

(NJ,NY,PR,VI)
OSHA Region 2
210 Varick Street, Room 670
New York, NY 10014
212-337-2376

(DE,DC,MD,PA,VA,WV)
OSHA Region 3
Gateway Building, Suite 2100
3535 Market Street
Philadelphia, PA 19104
215-596-1201

(AL,FL,GA,KY,MS,NC,SC,TN)
OSHA Region 4
1375 Peachtree Street, NE, Suite 587
Atlanta, GA 30367
404-347-3573

(IL,IN,MI,MN,OH,WI)
OSHA Region 5
230 South Dearborn Street, Room 3244
Chicago, IL 60604
312-353-2220

(AR,LA,NM,OK,TX)
OSHA Region 6
525 Griffin Street, Room 602
Dallas, TX 75202
214-767-4731

(IA,KS,MO,NE)
OSHA Region 7
911 Walnut Street, Room 406
Kansas City, MO 64106
816-426-5861

(CO,MT,ND,SD,UT,WY)
OSHA Region 8
Federal Building, Room 1576
1961 Stout Street
Denver, CO 80294
303-844-3061

(AZ,CA,HI,NV,AS,GU)
OSHA Region 9
71 Stevenson Street, 4th Floor
San Francisco, CA 94105
415-744-6570

(AK,ID,OR,WA)
OSHA Region 10
1111 Third Avenue, Suite 715
Seattle, WA 98101-3212
206-442-5930

OTHER FEDERAL AGENCIES WITH INDOOR AIR RESPONSIBILITIES

Bonneville Power Administration
P.O. Box 3621-RMRD
Portland, OR 97208
503-230-5475
Provides radon-resistant construction techniques, source control, and removal technology for indoor air pollutants.

Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, MD 20207
1-800-638-CPSC
Reviews complaints regarding the safety of consumer products and takes action to ensure product safety.

General Services Administration
18th and F Streets, NW
Washington, DC 20405
202-501-1464
Writes indoor air quality policy for Federal buildings. Provides proactive indoor air quality building assessments. Assesses complaints and provides remedial action.

U.S. Department of Energy
Office of Conservation and Renewable Energy
1000 Independence Avenue, SW, CE-43
Washington, DC 20585
202-586-9455
Quantifies the relationship among reduced infiltration, adequate ventilation, and acceptable indoor air quality.

U.S. Department of Health and Human Services
Office on Smoking and Health
National Center for Chronic Disease Prevention and Health Promotion
Centers for Disease Control
1600 Clifton Road, NE
Mail Stop K50
Atlanta, GA 30333
404-488-5705
Disseminates information about the health effects of passive smoking and strategies for eliminating exposure to environmental tobacco smoke.

Tennessee Valley Authority
Occupational Hygiene Department
328 Multipurpose Building
Muscle Shoals, AL 35660
205-386-2314
Provides building surveys and assessments associated with employee indoor air quality complaints.

STATE AND LOCAL AGENCIES

Your questions and concerns about indoor air problems can frequently be answered most readily by the government agencies in your State or locality. Responsibilities for indoor air quality issues are usually divided among many different agencies. You will often find that calling or writing the agencies responsible for health or air quality control is the best way to start getting information from your State or local government. The EPA and Public Health Foundation publication, ***Directory of State Indoor Air Contacts***, lists State agency contacts. (See publications list for information on ordering this publication.)

PRIVATE SECTOR CONTACTS

The private sector organizations that have information for the public on indoor air quality issues in commercial and public buildings include the following:

Building Management Associations

Association of Physical Plant Administrators of Universities and Colleges
1446 Duke Street
Alexandria, VA 22314-3492
703-684-1446

Building Owners and Managers Association International
1201 New York Ave., NW, Suite 300
Washington, DC 20005
202-408-2684

Institute of Real Estate Management
430 North Michigan Avenue
Chicago, IL 60611
312-661-1930

International Council of Shopping Centers
1199 North Fairfax Street, Suite 204
Alexandria, VA 22314
703-549-7404

International Facilities Management Association
Summit Tower, Suite 1710
11 Greenway Plaza
Houston, TX 77046
713-623-4362

National Apartment Association
1111 14th Street, NW, Suite 900
Washington, DC 20005
202-842-4050

National Association of Industrial and Office Parks
1215 Jefferson Davis Highway, Suite 100
Arlington, VA 22202
703-979-3400

Professional and Standard Setting Organizations

Air and Waste Management Association
P.O. Box 2861
Pittsburgh, PA 15230
412-232-3444

Air-Conditioning and Refrigeration Institute
1501 Wilson Blvd., Suite 600
Arlington, VA 22209
703-524-8800

American Conference of Governmental Industrial Hygienists
6500 Glenway Avenue, Building D-7
Cincinnati, OH 45211
513-661-7881

American Industrial Hygiene Association
P.O. Box 8390
345 White Pond Drive
Akron, OH 44320
216-873-2442

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103
215-299-5571

American Society of Heating, Refrigerating, and Air-Conditioning Engineers
1791 Tullie Circle, NE
Atlanta, GA 30329
404-636-8400

National Conference of States on Building Codes and Standards, Inc.
505 Huntmar Park Drive, Suite 210
Herndon, VA 22070
703-437-0100

Product Manufacturers

Adhesive and Sealant Council
1627 K Street, NW, Suite 1000
Washington, DC 20006-1707
202-452-1500

Asbestos Information Association
1745 Jefferson Davis Highway, Room 509
Arlington, VA 22202
703-979-1150

Business Council on Indoor Air Quality
1225 19th Street, Suite 300
Washington, DC 20036
(202) 775-5887

Carpet and Rug Institute
310 Holiday Avenue
Dalton, GA 30720
404-278-3176

Chemical Specialties Manufacturers Association
1913 I Street, NW
Washington, DC 20006
202-872-8110

Electric Power Research Institute
P.O. Box 10412
Palo Alto, CA 94303
415-855-2902

Formaldehyde Institute, Inc.
1330 Connecticut Avenue, NW
Washington, DC 20036
202-822-6757

Foundation of Wall and Ceiling Industries
1600 Cameron Street
Alexandria, VA 22314-2705
703-548-0374

Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, IL 60631
312-399-8304

National Paint and Coatings Association
1500 Rhode Island Avenue, NW
Washington, DC 20005
202-462-6272

Thermal Insulation Manufacturers Association Technical Services
Air Handling Committee
1420 King Street
Alexandria, VA 22314
(703) 684-0474

Building Service Associations

Air-Conditioning and Refrigeration Institute
1501 Wilson Boulevard, 6th floor
Arlington, VA 22209
703-524-8800

Air-Conditioning Contractors of America
1513 16th Street, NW
Washington DC 20036
202-483-9370

American Consulting Engineers Council
1015 15th Street, NW, Suite 802
Washington, DC 20005
202-347-7474

Associated Air Balance Council
1518 K Street, NW
Washington, DC 20005
202-737-0202

Association of Energy Engineers
4025 Pleasantdale Rd., Suite 420
Atlanta, GA 30340
404-447-5083

Association of Specialists in Cleaning and Restoration International
10830 Annapolis Junction Road, Suite 312
Annapolis Junction, MD 20701
301-604-4411

National Air Duct Cleaners Association
1518 K Street, NW, Suite 503
Washington, DC 20005
202-737-2926

National Association of Power Engineers
3436 Haines Way, Suite 101
Falls Church, VA 22041
703-845-7055

National Energy Management Institute
601 North Fairfax Street, Suite 160

Alexandria, VA 22314
703-739-7100

National Environmental Balancing Bureau
1385 Piccard Drive
Rockville, MD 20850
301-977-3698

National Pest Control Association
8100 Oak Street
Dunn Loring, VA 22027
703-573-8330

Sheet Metal and Air Conditioning Contractors National Association
4201 LaFayette Center Drive
Chantilly, VA 22021
703-803-2980

Unions

AFL-CIO
Department of Occupational Safetyand Health
815 16th Street, NW
Washington, DC 20006
202-637-5000

American Federation of Government Employees
80 F Street, NW
Washington, DC 20001
202-737-8700

American Federation of State, County, and Municipal Employees
1625 L Street, NW
Washington, DC 20036
(202) 429-1215

American Federation of Teachers
555 New Jersey Avenue, NW
Washington, DC 20001
202-879-4400

Communication Workers of America
501 3rd Street, NW
Washington, DC 20001
202-434-1160

International Union of Operating Engineers
1125 17th Street, NW
Washington, DC 20036
202-429-9100

Service Employees International Union
1313 L Street, NW
Washington, DC 20005

Environmental/Health/ Consumer Organizations

American Academy of Allergy and Immunology
611 East Wells Street
Milwaukee, WI 53202
414-272-6071

American Lung Association
or your local lung association
1740 Broadway
New York, NY 10019

Consumer Federation of America
1424 16th Street, NW, Suite 604
Washington, DC 20036

National Center for Environmental Health Strategies
1100 Rural Avenue
Voorhees, NJ 08043
609-429-5358

National Environmental Health Association
720 South Colorado Blvd.
South Tower, Suite 970
Denver, CO 80222
303-756-9090

National Foundation for the Chemically Hypersensitive
P.O. Box 9
Wrightsville Beach, NC 28480
517-697-3989

Occupational Health Foundation
1126 16th Street, NW
Washington, DC 20036
202-842-7840

PUBLICATIONS

Items marked * are available from **EPA Public Information Center** (PM-211B), 401 M Street, SW, Washington, DC 20460. 202-382-2080.

Items marked ** are available from **TSCA Assistance Hotline** (TS-799), 401 M Street, SW, Washington, DC 20460. (202)554-1404.

Items marked*** are available from **NIOSH Publications Dissemination,** 4676 Columbia Parkway, Cincinnati, OH 45202. 513-533-8287.

General Information

Cone, James E. and Michael J. Hodgson, MD, MPH. ***Problem Buildings: Building-Associated Illness and the Sick Building Syndrome.*** 1989. From the series "Occupational Medicine: State of the Art Reviews." Hanley & Belfus, Inc., 210 South 13th Street, Philadelphia, PA 19107.

Godish, Thad. ***Indoor Air Pollution Control.*** 1989. Lewis Publishers, 121 South Main Street, Chelsea, MI 48118.

Rajhans, G.S., ***Report of the Interministerial Committee on Indoor Air Quality,*** 1988. Contact: G. Rajhans, Health and Safety Support Services Branch, Ministry of Labour, 400 University Avenue, 7th Floor, Toronto, Ontario, Canada M7A 1T7.

Sheet Metal and Air Conditioning Contractor's National Association, Inc. (SMACNA). ***Indoor Air Quality.*** 1988. 8224 Old Courthouse Road, Vienna, Virginia 22180.

U.S. Environmental Protection Agency. and the Public Health Foundation. ***Directory of State Indoor Air Contacts.*** Updated, 1991. *

U.S. Environmental Protection Agency. ***Designing for Good Indoor Air Quality: An Introduction for Design Professionals.*** (In progress).

U.S. Environmental Protection Agency. ***Project Summaries: Indoor Air Quality in Public Buildings.*** 1988. *Contains findings of research on IAQ in 10 new public and commercial buildings and on building material emissions.**

U.S. Environmental Protection Agency and the U.S. Consumer Product Safety Commission. ***The Inside Story: A Guide to Indoor Air Quality.*** 1988. *Addresses residential indoor air quality primarily, but contains a section on offices.* *

U.S. Environmental Protection Agency. ***Sick Building Syndrome.*** Indoor Air Quality Fact Sheet #4. Revised, 1991.*

U.S. Environmental Protection Agency. ***Ventilation and Air Quality in Offices.*** Indoor Air Quality Fact Sheet #3. Revised, 1990.*

World Health Organization. ***Air Quality Guidelines for Eiurope.*** 1987. WHO Regional Publications, European Series No. 23. Available from WHO Publications Center USA, 49 Sheridan Avenue, Albany, NY 12210.

Asbestos

Keyes, Dale L. and Jean Chesson. ***A Guide to Monitoring Airborne Asbestos in Buildings.*** 1989. Environmental Sciences, Inc., 105 E. Speedway Blvd., Tucson, Arizona 85705.

U.S. Department of Health and Human Services, Public Health Service, U.S. Centers for Disease Control, National Institute of Occupational Safety and Health. ***Testimony of NIOSH on the Occupational Safety and Health Administration's Proposed Rule on Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite.*** June 1984, May 1990, and January 1991. NIOSH Docket Office, C-34, 4676 Columbia Parkway, Cincinnati, OH 45226.

U.S. Environmental Protection Agency. ***A Guide to Respiratory Protection for the Asbestos Abatement Industry.*** 1986. EPA 560/OTS 86-001. **

U.S. Environmental Protection Agency. ***Abatement of Asbestos-Containing Pipe Insulation.*** 1986. Technical Bulletin No. 1986-2. **

U.S. Environmental Protection Agency. ***Asbestos Abatement Projects: Worker Protection.*** Final Rule 40 CFR. 763. February 1987. **

U.S. Environmental Protection Agency. ***Asbestos Ban and Phaseout Rule.*** 40 CFR 763.160 to 763.179. Federal Register, July 12, 1989. **

U.S. Environmental Protection Agency. ***Asbestos in Buildings: Guidance for Service and Maintenance Personnel*** (in English and Spanish). 1985. EPA 560/5-85-018. ("Custodial Pamphlet"). **

U.S. Environmental Protection Agency. ***Asbestos in Buildings: Simplified Sampling Scheme for Surfacing Materials.*** 1985. 560/5-85-030A. ("Pink Book"). **

U.S. Environmental Protection Agency. ***Guidance for Controlling Asbestos-Containing Materials in Buildings.*** 1985. EPA 560/5-85-024. ("Purple Book"). **

U.S. Environmental Protection Agency. ***Guidelines for Conducting the AHERA TEM Clearance Test to Determine Completion of an Asbestos Abatement Project,*** EPA 560/5-89-001. **

U.S. Environmental Protection Agency. ***Managing Asbestos In Place: A Building Owner's Guide to Operations and Maintenance Programs for Asbestos-Containing Materials,*** 1990. ("Green Book").**

U.S. Environmental Protection Agency. ***Measuring Airborne Asbestos Following An Abatement Action.*** 1985. EPA 600/4-85-049. ("Silver Book"). **

U.S. Environmental Protection Agency. ***National Emission Standards for Hazardous Air Pollutants.*** 40 Code of Federal Regulation 61. April 1984. **

U.S. Environmental Protection Agency. ***Transmission Electron Microscopy Asbestos Laboratories: Quality Assurance Guidelines.*** 1989. EPA 560/5-90-002.**

U.S. Department of Labor. OSHA Regulations. 29 Code of Federal Regulation 1910.1001. ***General Industry Asbestos Standard*** . 29 Code of Federal Regulation 1926.58. ***Construction Industry Asbestos Standard.*** June 1986; Amended September 1988. DOL-OSHA Docket, 200 Constitution Avenue, NW, Room N 2625, Washington, DC 20210

U.S. Department of Labor. OSHA Regulations. 29 Code of Federal Regulation 1910.134 ***Respiratory Protection Standard.*** June 1974. DOL-OSHA Docket, 200 Constitution Avenue, NW, Room N 2625, Washington, DC 20210

Biologicals

American Council of Governmental Industrial Hygienists. ***Guidelines for the Assessment of Bioaerosols in the Indoor Environment.*** 1989. 6500 Glenway Avenue, Building D-7, Cincinnati, OH 45211.

Morey, P., J. Feeley, and J. Otten. ***Biological Contaminants in Indoor Environments.*** 1990. American Society for Testing and Materials Publications, 1916 Race Street, Philadelphia, PA 19103.

Building Management, Investigation, and Remediation

Bazerghi, Hani and Catherine Arnoult. ***Practical Manual for Good Indoor Air Quality.*** 1989. Quebec Association for Energy Management. 1259 Berri Street, Suite 510, Montreal, Quebec, Canada, H2L 4C7.

Hansen, Shirley J., ***Managing Indoor Air Quality.*** 1991. Fairmont Press, 700 Indian

Trail, Lilburn, GA 30247.

U.S. Department of Health and Human Services. Public Health Service. Centers for Disease Control. National Institute for Occupational Safety and Health. ***Indoor Air Quality: Selected References.*** 1989.***

U.S. Department of Health and Human Services. Public Health Service. Centers for Disease Control. National Institute for Occupational Safety and Health. ***Guidance for Indoor Air Quality Investigations.*** 1987.***

Weekes, Donald M. and Richard B. Gammage. ***The Practitioner's Approach to Indoor Air Quality Investigations.*** Proceedings of the Indoor Air Quality International Symposium. 1989. American Industrial Hygiene Association, P.O. Box 8390, Akron Ohio 44320.

Environmental Tobacco Smoke

National Research Council. ***Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects.*** 1986. National Academy Press. 2001 Wisconsin Avenue, NW, Washington, DC 20418.

U.S. Department of Health and Human Services. Public Health Service. Office on Smoking and Helath. ***The Health Consequences of Involuntary Smoking, A Report of the Surgeon General.*** 1986. 1600 Clifton Road, NE (Mail Stop K50) Atlanta, GA 30333.

U.S. Department of Health and Human Services, Public Health Service. Centers for Disease Control, National Institute for Occupational Safety and Health. ***Current Intelligence Bulletin 54: Environmental Tobacco Smoke in the Workplace—Lung Cancer and Other Health Effects.*** DHHS (NIOSH) Publication No. 91-108. 1991.***

U.S. Department of Health and Human Services, National Cancer Institute. Office of Cancer Communications. ***A series of one-page information sheets on all aspects of smoking in the workplace.*** For copies, call 1-800-4-CANCER.

U.S. Environmental Protection Agency. ***Environmental Tobacco Smoke.*** Indoor Air Quality Fact Sheet #5. 1989.*

U.S. Environmental Protection Agency. ***Environmental Tobacco Smoke: A Guide to the Development of Effective Smoking Policies.*** (In progress.) *

U.S. Environmental Protection Agency. ***Health Effects of Passive Smoking: Assessment of Lung Cancer in Adults and Respiratory Disorders in Children.*** (In progress.) *

PCBs

U.S. Department of Health And Human Services. Public Health Service. Centers for Disease Control.. National Institute of Occupational Safety and Health. ***Current Intelligence Bulletin 45: Polychlorinated Biphenyls—Potential Health Hazards from Electrical Equipment Fires or Failures*** . DHHS (NIOSH) Publication No. 86-111. 1977. Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

U.S. Department of Health and Human Services. Public Health Service. Centers for Disease Control. National Institute for Occupational Safety and Health. ***A Recommended Standard for Occupational Exposure to Polychlorinated Biphenyls*** DHHS (NIOSH) Publication No. 77-225. 1977. Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

U.S. Environmental Protection Agency. ***Transformers and the Risk of Fire: A Guide for Building Owners.*** 1986. OPA/86-001. **

Radon

U.S. Environmental Protection Agency.

State Proficiency Report. 1991. EPA 520/1-94-014. Available from State radon offices. *List of laboratories that have demonstrated com- petence in radon measurement analysis.*

Standards and Guidelines

American Conference of Government Industrial Hygienists. ***Threshold Limit Values and Biological Exposure Indices.*** 1990-1991. 6500 Glenway Avenue, Building D-7, Cincinnati, OH 45211.

U.S. Department of Health and Human Services. Public Health Service. Centers for Disease Control. National Institute for Occupational Safety and Health . ***NIOSH Recommendations for Occupational Safety and Health. Compendium of Policy Documents and Statements.*** DHHS (NIOSH) Publications 91-109. 1991.***

U.S. Department of Labor. OSHA Rrgulations. 29 CFR Part 1910.1000. ***OSHA Standards for Air Contaminants.*** Available from the U.S. Government Printing Office, Washington, DC 20402. 202-783-3238. *Additional health standards for some specific air contaminants are also available in Subpart Z.*

Ventilation/Thermal Comfort

Brief descriptions of the ASHRAE standards listed below are included in *Appendix B.* ASHRAE materials are available from their Publication Sales Department, 1791 Tullie Circle, NE, Atlanta, GA 30329. 404-636-8400.

ASHRAE Guideline 1-1989. ***Guideline for the Commissioning of HVAC Systems.*** 1989.
ASHRAE Journal. ***October 1989 issue.*** *Several articles describing ASHRAE Standard 62-1989.*

ASHRAE Standard 52-76. ***Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter.*** 1976.

ASHRAE Standard 55-1981. ***Thermal Environmental Conditions for Human Occupancy.*** 1981.

ASHRAE Standard 62-1989. ***Ventilation for Acceptable Indoor Air Quality.*** 1989.

National Conference of States on Building Codes and Standards, Inc. ***The Ventilation Directory.*** 505 Huntmar Park Drive, Suite 210, Herndon, VA 22070. 703-481-2020. *Summarizes natural, mechanical, and exhaust ventilation requirements of the model codes, ASHRAE standards, and unique State codes.*

TRAINING

American Industrial Hygiene Association (AIHA). P.O. Box 8390, 345 White Pond Drive, Akron, OH 44320. 216-873-2442. *Sponsors indoor air quality courses in conjunction with meetings for AIHA members only.*

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 1791 Tullie Circle NE, Atlanta, GA 30329. 404-636-8400. *Sponsors professional development seminars on indoor air quality.*

NIOSH Division of Training and Manpower Development and NIOSH-funded Educational Resource Centers. 4676 Columbia Parkway, Cincinnati, OH 45226. 513-8221. *Provide training to occupational safety and health professionals and paraprofessionals.*

OSHA Training Institute. 155 Times Drive, Des Plaines, Il 60018. 708-297-4913. *Provides courses to assist health and safety professionals in evaluating indoor air quality.*

Indoor Air Quality Forms

This section of the document is a collection of the forms that appear or are mentioned in the text. Consider making copies of the forms, blocking out the page information at the bottom of the copies, and then reproducing these copies for use in your building. Some or all of them may require adaptation to meet your specific needs. Blank formatted sheets are included for preparing your own *HVAC Checklist* and *Pollutant and Source Inventory*.

The forms appear in the following sequence:

Management Checklist: (4 pages): for keeping track of the elements of the IAQ profile and IAQ management plan.

Pollutant Pathway Record For IAQ Profiles: for identifying areas in which negative or positive pressures should be maintained.

Zone/Room Record: for recording information on a room-by-room basis on the topics of room use, ventilation, and occupant population.

Ventilation Worksheet: to be used in conjunction with the Zone/Room Record when calculating quantities of outdoor air that are being supplied to individual zones or rooms.

IAQ Complaint Form: to be filled out by the complainant or by a staff person who receives information from the complainant.

Incident Log: for keeping track of each IAQ complaint or problem and how it is handled.

Occupant Interview (2 pages): for recording the observations of building occupants in relation to their symptoms and conditions in the building .

Occupant Diary: for recording incidents of symptoms and associated observations as they occur.

Log of Activities and System Operation: for recording activities and equipment operating schedules as they occur.

HVAC Checklist - Short Form (4 pages): to be used as a short form for investigating an IAQ problem, or for periodic inspections of the HVAC system. Duplicate pages 2 through 4 for each large air handling unit.

HVAC Checklist - Long Form (14 pages, followed by one blank formatted sheet): to be used for detailed inspections of the HVAC system or as a long form for investigating an IAQ problem. Duplicate pages 1 through 11 for each large air handling unit.

Pollutant Pathway Form For Investigations: to be used in conjunction with a floor plan of the building.

Pollutant and Source Inventory (6 pages, followed by one blank formatted sheet): to be used as a general checklist of potential indoor and outdoor pollutant sources.

Chemical Inventory: for recording information about chemicals stored or used within the building.

Hypothesis Form: to be used for summarizing what has been learned during the building investigation, a tool to help the investigator collect his or her thoughts.

BLANK FORMS

Building Air Quality

IAQ Management Checklist

Building Name: ______________________________ Date: ______________

Address: ____

Completed by (name/title): ______________________________

Use this checklist to make sure that you have included all necessary elements in your IAQ profile and IAQ management plan. *Sections 4 and 5* discuss the development of the IAQ profile and IAQ management plan.

Item	Date begun or completed (as applicable)	Responsible person (name, telephone)	Location ("NA" if the item is not applicable to this building)
IAQ PROFILE			
Collect and Review Existing Records			
HVAC design data, operating instructions and manuals			
HVAC maintenance and calibration records, testing and balancing reports			
Inventory of locations where occupancy, equipment, or building use has changed			
Inventory of complaint locations			
Conduct a Walkthrough Inspection of the Building			
List of responsible staff and/or contractors, evidence oftraining, and job descriptions			
Identification of area where positive or negative pressure should be maintained			
Record of locations that need monitoring or correction			
Collect Detailed Information			
Inventory of HVAC system components needing repair, adjustment, or replacement			
Record of control settings and operating schedules			

IAQ Management Checklist

Item	Date begun or completed (as applicable)	Responsible person (name, telephone)	Location ("NA" if the item is not applicable to this building)
Plan showing airflow directions or pressure differentials in significant areas			
Inventory of significant pollutant sources and their locations			
MSDSs for supplies and hazardous substances that are stored or used in the building			
Zone/Room Record			
IAQ MANAGEMENT PLAN			
Select IAQ Manager			
Review IAQ Profile			
Assign Staff Responsibilities/ Train Staff			
Facilities Operation and Maintenance			
n confirm that equipment operating schedules are appropriate			
n confirm appropriate pressure relationships between building usage areas			
n compare ventilation quantities to design, codes, and ASHRAE 62-1989			
n schedule equipment inspections per preventive maintenance or recommended maintenance schedule			
n modify and use HVAC Checklist(s); update as equipment is added, removed, or replaced			
n schedule maintenance activities to avoid creating IAQ problems			

IAQ Management Checklist

Item	Date begun or completed (as applicable)	Responsible person (name, telephone)	Location ("NA" if the item is not applicable to this building)
n review MSDSs for supplies; request additional information as needed			
n consider using alarms or other devices to signal need for HVAC maintenance (e.g., clogged filters)			
Housekeeping			
n evaluate cleaning schedules and procedures; modify if necessary			
n review MSDSs for products in use; buy different products if necessary			
n confirm proper use and storage of materials			
n review trash disposal procedures; modify if necessary			
Shipping and Receiving			
n review loading dock procedures (*Note:* If air intake is located nearby, take precautions to prevent intake of exhaust fumes.)			
n check pressure relationships around loading dock			
Pest Control			
n consider adopting IPM methods			
n obtain and review MSDSs; review handling and storage			
n review pest control schedules and procedures			
n review ventilation used during pesticide application			

IAQ Management Checklist

Item	Date begun or completed (as applicable)	Responsible person (name, telephone)	Location ("NA" if the item is not applicable to this building)
Occupant Relations			
n establish health and safety committee or joint tenant/ management IAQ task force			
n review procedures for responding to complaints; modify if necessary			
n review lease provisions; modify if necessary			
Renovation, Redecorating, Remodeling			
n discuss IAQ concerns with architects, engineers, contractors, and other professionals			
n obtain MSDSs; use materials and procedures that minimize IAQ problems			
n schedule work to minimize IAQ problems			
n arrange ventilation to isolate work areas			
n use installation procedures that minimize emissions from new furnishings			
Smoking			
n eliminate smoking in the building			
n if smoking areas are designated, provide adequate ventilation and maintain under negative pressure			
n work with occupants to develop appropriate non-smoking policies, including implementation of smoking cessation programs			

Pollutant Pathway Record For IAQ Profiles

This form should be used in combination with a floor plan such as a fire evacuation plan.

Building Name: ____ File Number: ________________________

Address: ____

Completed by:_______________________________________ Title: _______________________ Date: _______________

Sections 2, 4 and 6 discuss pollutant pathways and driving forces.

Building areas that contain contaminant sources (e.g., bathrooms, food preparation areas, smoking lounges, print rooms, and art rooms) should be maintained under negative pressure relative to surrounding areas. Building areas that need to be protected from the infiltration of contaminants (e.g., hallways in multi-family dwellings, computer rooms, and lobbies) should be maintained under positive pressure relative to the outdoors and relative to surrounding areas.

List the building areas in which pressure relationships should be controlled. As you inspect the building, put a Y or N in the "Needs Attention" column to show whether the desired air pressure relationship is present. Mark the floor plan with arrows, plus signs (+) and minus signs (-) to show the airflow patterns you observe, using chemical smoke or a micromanometer.

Building areas that appear isolated from each other may be connected by airflow passages such as air distribution zones, utility tunnels or chases, party walls, spaces above suspended ceilings (whether or not those spaces are serving as air plenums), elevator shafts, and crawlspaces. If you are aware of pathways connecting the room to identified pollutant sources (e.g., items of equipment, chemical storage areas, bathrooms), it may be helpful to record them in the "Comments" column, on the floor plan, or both.

Building Area (zone, room)	Use	Intended Pressure		Needs Attention? (Y/N)	Comments
		Positive (+)	Negative (-)		

Zone/Room Record

Building Name: ______________________ File Number: ______________________ Date: ______________________

Address: ______________________ Completed by: ______________________ Title: ______________________

This form is to be used differently depending on whether the goal is to prevent or to diagnose IAQ problems. During the development of a profile, this form should be used to record more general information about the entire building; during an investigation, the form should be used to record more detailed information about the complaint area and areas surrounding the complaint area or connected to it by pathways.

Use the last three columns when underventilation is suspected. Use the Ventilation Worksheet and Appendix A to estimate outdoor air quantities Compare results to the design specifications, applicable building codes, or ventilation guidelines such as ASHRAE 62-1989. (See Appendix A for some outdoor air quantities required by ASHRAE 62-1989.) Note: For VAV systems, minimum outdoor air under reduced flow conditions must be considered.

PROFILE AND DIAGNOSIS INFORMATION					DIAGNOSIS INFORMATION ONLY		
Building Area (Zone/Room)	Use**	Source of Outdoor Air*	Mechanical Exhaust? (Write "No" or estimate cfm airflow)	Comments	Peak Number of Occupants or Sq. Ft. Floor Area**	Total Air Supplied (in cfm)***	Outdoor Air Supplied per Person or per 150 Sq. Ft. Area (in cfm)****

* Sources might include air handling unit (e.g., AHU-4), operable windows, transfer from corridors.
** Underline the information in this column if corrent use or number of occupants is different from design specifications.
*** Mark the information with a P if it comes from the mechanical plans or an M if it comes from actual measurements, such as recent test and balance reports.
**** ASHRAE 62-1989 gives ventilation guidance per 150 sq. ft.

Ventilation Worksheet

Building Name: ____________________ File Number: ____________

Address: ______________________________

Completed by (name):____________________ Date: ____________

This worksheet is designed for use with the **Zone/Room Record.** Appendix A provides guidance on methods of estimating the amount of ventilation (outdoor) air being introduced by a particular air handling unit. Appendix B discusses the ventilation recommendations of ASHRAE Standard 62-1989, which was developed for the purpose of preventing indoor air quality problems. Formulas are given below for calculating outdoor air quantities using thermal or CO_2 information.

The equation for calculating outdoor air quantities using thermal measurements is:

$$\text{Outdoor air (in percent)} = \frac{T_{\text{return air}} - T_{\text{mixed air}}}{T_{\text{return air}} - T_{\text{outdoor air}}} \times 100$$

Where: T = temperature in degrees Fahrenheit

The equation for calculating outdoor quantities using carbon dioxide measurements is:

$$\text{Outdoor air (in percent)} = \frac{C_s - C_r}{C_0 - C_r} \times 100$$

Where: C_s= ppm of carbon dioxide in the supply air (if measured in a room), or
C_s= ppm of carbon dioxide in the mixed air (if measured at an air handler)
C_r= ppm of carbon dioxide in the return air
C_o= ppm of carbon dioxide in the outdoor air

Using the table below to estimate the ventilation rate in any room or zone. Note: ASHRAE 62-1989 generally states ventilation (outdoor air) requirements on an occupancy basis; for a few types of spaces, however, requirements are given on a floor area basis. Therefore, this table provides a process of calculating ventilation (outdoor air) on either an occupancy or floor area basis.

Zone/Room	Percent of Outdoor Air A	Total Air Supplied to Zone/Room (cfm) B	Peak Occupancy (number of people) or Floor Area (square feet) C	$D = \frac{B}{C}$ Total Air Supplied Per Person (or per square foot area) D	E = (Ax100) x D Outdoor Air Supplied Per Person (or per square foot area) E

Indoor Air Quality Complaint Form

This form can be filled out by the building occupant or by a member of the building staff.

Occupant Name: ____ Date: ________________________

Department/Location in Building: ____ Phone: ______________________

Completed by: ________________________________ Title: ______________________ Phone: __________________

This form should be used if your complaint may be related to indoor air quality. Indoor air quality problems include concerns with temperature control, ventilation, and air pollutants. Your observations can help to resolve the problem as quickly as possible. Please use the space below to describe the nature of the complaint and any potential causes.

We may need to contact you to discuss your complaint. What is the best time to reach you? _________________________

So that we can respond promptly, please return this form to: ____

IAQ Manager or Contact Person

____

Room, Building, Mail Code

OFFICE USE ONLY

File Number: _________________________ Received By: ________________________________ Date Received: __________

Incident Log

Building Name: ______________________ Dates (from): ____________ (to): ____________

Address: ______________________ Completed by (name):______________________

File Number	Date	Problem Location	Investigation Record (check the forms that were used)									Outcome/Comments (use more than one line if needed)	Log Entry By (initials)
			Complaint Form	Occupant Interview	Occupant Diary	Log of Activities	Zone/Room Record	HVAC Checklist	Pollutant Pathway	Source Inventory	Hypothesis Form		

Occupant Interview

Building Name: ____ File Number: ____________________

Address: ____

Occupant Name: _________________________________ Work Location: _______________________________

Completed by:________________________________ Title: _____________________ Date:_____________

Sections 4 discusses collecting and interpreting information from occupants.

SYMPTOM PATTERNS

What kind of symptoms or discomfort are you experiencing?

Are you aware of other people with similar symptoms or concerns? Yes __________ No __________

If so, what are their names and locations? ____

____

Do you have any health conditions that may make you particularly susceptible to environmental problems?

q contact lenses
q allergies
q chronic cardiovascular disease
q chronic respiratory disease
q chronic neurological problems
q undergoing chemotherapy or radiation therapy
q immune system suppressed by disease or other causes

TIMING PATTERNS

When did your symptoms start?

When are they generally worst?

Do they go away? If so, when?

Have you noticed any other events (such as weather events, temperature or humidity changes, or activities in the building) that tend to occur around the same time as your symptoms?

Occupant Interview

SPATIAL PATTERNS

Where are you when you experience symptoms or discomfort?

Where do you spend most of your time in the building?

ADDITIONAL INFORMATION

Do you have any observations about building conditions that might need attention or might help explain your symptoms (e.g., temperature, humidity, drafts, stagnant air, odors)?

Have you sought medical attention for your symptoms?

Do you have any other comments?

Occupant Diary

Occupant Name:___________________________ Title: ___________________________ Phone: _____________________

Location: ____ File Number: _____________________________

On the form below, please record each occasion when you experience a symptom of ill-health or discomfort that you think may be linked to an environmental condition in this building.

It is important that you record the time and date and your location within the building as accurately as possible, because that will help to identify conditions (e.g., equipment operation) that may be associated with your problem. Also, please try to describe the severity of your symptoms (e.g., mild, severe) and their duration (the length of time that they persist). Any other observations that you think may help in identifying the cause of the problem should be noted in the "Comments" column. Feel free to attach additional pages or use more than one line for each event if you need more room to record your observations.

Section 6 discusses collecting and interpreting occupant information.

Time/Date	**Location**	**Symptom**	**Severity/Duration**	**Comments**

Log of Activities and System Operations

Building Name: ________________________ Address: ___________________________ File Number:_________________

Completed by:__________________________________ Title: __________________________ Phone: _________________

On the form below, please record your observations of the HVAC system operation, maintenance activities, and any other information that you think might be helpful in identifying the cause of IAQ complaints in this building. Please report any other observations (e.g., weather, other associated events) think may be important as well.

Feel free to attach additional pages or use more than one line for each event.

Equipment and activities of particular interest:

Air Handler(s): ____

Exhaust Fan(s): ____

Other Equipment or Activities: ____

Date/Time	**Day of Week**	**Equipment Item/Activity**	**Observations/Comments**

HVAC Checklist - Short Form

Building Name: ________________________________ Address: ________________________________

Completed by: ________________________________ Date: __________ File Number: ______________

Sections 2, 4 and 6 and Appendix B discuss the relationships between the HVAC system and indoor air quality.

MECHANICAL ROOM

- Clean and dry? ________________________ Stored refuse or chemicals? ________________________
- Describe items in need of attention ____

MAJOR MECHANICAL EQUIPMENT

- Preventive maintenance (PM) plan in use? ____

Control System

- Type ____
- System operation ____
- Date of last calibration ____

Boilers

- Rated Btu input __________ Condition ____
- Combustion air: is there at least one square inch free area per 2,000 Btu input? ________________________
- Fuel or combustion odors ____

Cooling Tower

- Clean? no leaks or overflow? __________________ Slime or algae growth? ________________________
- Eliminator performance ____
- Biocide treatment working? (list type of biocide) ____
- Spill containment plan implemented? __________________ Dirt separator working? ________________________

Chillers

- Refrigerant leaks? ____
- Evidence of condensation problems? ____
- Waste oil and refrigerant properly stored and disposed of? ____

HVAC Checklist - Short Form

Building Name: ______________________________ Address: ______________________________

Completed by: ______________________________ Date: __________ File Number: ______________

AIR HANDLING UNIT

- Unit identification ______________________ Area served ______________________

Outdoor Air Intake, Mixing Plenum, and Damper

- Outdoor air intake location ______________________
- Nearby contaminant sources? (describe) ______________________
- Bird screen in place and unobstructed? ______________________
- Design total cfm __________ outdoor air (O.A.) cfm __________ date last tested and balanced __________
- Minimum % O.A. (damper setting) __________ Minimum cfm O.A. $\frac{\text{(total cfm x minimum \% O.A.)}}{100}$ = __________
- Current O.A. damper setting (date, time, and HVAC operating mode) ______________________
- Damper control sequence (describe) ______________________
- Condition of dampers and controls (note date) ______________________

Fans

- Control sequence ______________________
- Condition (note date) ______________________
- Indicated temperatures supply air ______ mixed air ______ return air ______ outdoor air ______
- Actual temperatures supply air ______ mixed air ______ return air ______ outdoor air ______

Coils

- Heating fluid discharge temperature ________ ΔT ______ cooling fluid discharge temperature ______ ΔT ______
- Controls (describe) ______________________
- Condition (note date) ______________________

Humidifier

- Type ______________________ if biocide is used, note type ______________________
- Condition (no overflow, drains trapped, all nozzles working?) ______________________
- No slime, visible growth, or mineral deposits? ______________________

HVAC Checklist - Short Form

Building Name: ________________________ Address: ________________________

Completed by: ________________________ Date: __________ File Number: __________

DISTRIBUTION SYSTEM

Zone/ Room	System Type	Supply Air		Return Air		Power Exhaust		
		ducted/ unducted	cfm*	ducted/ unducted	cfm*	cfm*	control	serves (e.g. toilet)

Condition of distribution system and terminal equipment (note locations of problems)

- Adequate access for maintenance? ________________________
- Ducts and coils clean and obstructed? ________________________
- Air paths unobstructed? supply ______ return ______ transfer ______ exhaust ______ make-up ______
- Note locations of blocked air paths, diffusers, or grilles ________________________
- Any unintentional openings into plenums? ________________________
- Controls operating properly? ________________________
- Air volume correct? ________________________
- Drain pans clean? Any visible growth or odors? ________________________

Filters

Location	Type/Rating	Size	Date Last Changed	Condition (give date)

HVAC Checklist - Short Form

Building Name: ____________________ Address: ____________________

Completed by: ____________________ Date: __________ File Number: __________

OCCUPIED SPACE

Thermostat types ____________________

Zone/ Room	Thermostat Location	What Does Thermostat Control? (e.g., radiator, AHU-3)	Setpoints		Measured Temperature	Day/ Time
			Summer	Winter		

Humidistats/Dehumidistats type ____________________

Zone/ Room	Humidistat/ Dehumidistat Location	What Does It Control?	Setpoints (%RH)	Measured Temperature	Day/ Time

- Potential problems (note location) ____________________
- Thermal comfort or air circulation (drafts, obstructed airflow, stagnant air, overcrowding, poor thermostat location)

____

____

- Malfunctioning equipment ____________________
- Major sources of odors or contaminants (e.g., poor sanitation, incompatible uses of space)

____

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: ____________________ Date Checked: __________

Appendix B discusses HVAC system components in relation to indoor air quality.

Component	OK	Needs Attention	Not Applicable	Comments
Outside Air Intake				
Location ______________ ______________				
Open during occupied hours?				
Unobstructed?				
Standing water, bird droppings in vicinity?				
Odors from outdoors? (describe) ______________ ______________				
Carryover of exhaust heat?				
Cooling tower within 25 feet?				
Exhaust outlet within 25 feet?				
Trash compactor within 25 feet?				
Near parking facility, busy road, loading dock?				
Bird Screen				
Unobstructed?				
General condition?				
Size of mesh? (½" minimum)				
Outside Air Dampers				
Operation acceptable?				
Seal when closed?				

HVAC Checklist - Long Form

Building: ____ File Number: _________________________

Completed by: ___________________________ Title: _______________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Actuators operational?				
Outdoor Air (O.A.) Quantity ***(Check against applicable codes and ASHRAE 62-1989.)***				
Minimum % O.A. _______________				
Measured % O.A. _______________ *Note day, time, HVAC operating mode under "Comments"*				
Maximum % O.A. _______________				
Is minimum O.A. a separate damper?				
For VAV systems: is O.A. increased as total system air-flow is reduced?				
Mixing Plenum				
Clean?				
Floor drain trapped?				
Airtightness				
■ of outside air dampers				
■ of return air dampers				
■ of exhaust air dampers				
All damper motors connected?				
All damper motors operational?				
Air mixers or opposed blades?				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: __________________ Date Checked: ________

Component	OK	Needs Attention	Not Applicable	Comments
Mixed air temperature control setting ________ °F				
Freeze stat setting ______ °F				
Is mixing plenum under negative pressure? *Note: If it is under positive pressure, outdoor air may not be entering.*				
Filters				
Type ____________________				
Complete coverage? (i.e., no bypassing)				
Correct pressure drop? *(Compare to manufacturer's recommendations.)*				
Contaminants visible?				
Odor noticeable?				
Spray Humidifiers or Air Washers				
Humidifier type				
All nozzles working?				
Complete coil coverage?				
Pans clean, no overflow?				
Drains trapped?				
Biocide treatment working? *Note: Is MSDS on file?* __________				
Spill contaminant system in place?				

HVAC Checklist - Long Form

Building: ____ File Number: _________________________

Completed by: ___________________________ Title: _______________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Face and Bypass Dampers				
Damper operation correct?				
Damper motors operational?				
Cooling Coil				
Inspection access?				
Clean?				
Supply water temp. _____ ^{o}F				
Water carryover?				
Any indication of condensation problems?				
Condensate Drip Pans				
Accessible to inspect and clean?				
Clean, no residue?				
No standing water, no leaks?				
Noticeable odor?				
Visible growth (e.g., slime)?				
Drains and traps clear, working?				
Trapped to air gap?				
Water overflow?				

HVAC Checklist - Long Form

Building: ____ File Number: _________________________

Completed by: ___________________________ Title: _______________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Mist Eliminators				
Clean, straight, no carryover?				
Supply Fan Chambers				
Clean?				
No trash or storage?				
Floor drain traps are wet or sealed?				
No air leaks?				
Doors close tightly?				
Supply Fans				
Location ___________________				
Fan blades clean?				
Belt guards installed?				
Proper belt tension?				
Excess vibration?				
Corrosion problems?				
Controls operational, calibrated?				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: ____________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Control sequence conforms to design/specifications? (describe changes)				
No pneumatic leaks?				
Heating Coil				
Inspection access?				
Clean?				
Contol sequence conforms to design/specifications? (describe changes)				
Supply water temp. _____ ^oF				
Discharge thermostat? (air temp. setting _______ ^oF)				
Reheat Coils				
Clean?				
Obstructed?				
Operational?				
Steam Humidifier				
Humidifier type				
Treated boiler water				
Standing water?				

HVAC Checklist - Long Form

Building: ____ File Number: __________________________

Completed by: ____________________________ Title: ________________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Visible growth?				
Mineral deposits?				
Control setpoint ________ °F				
High limit setpoint ______ °F				
Duct liner within 12 feet? (If so, check for dirt, mold growth.)				
Supply Ductwork				
Clean?				
Sealed, no leaks, tight connections?				
Fire dampers open?				
Access doors closed?				
Lined ducts?				
Flex duct connected, no tears?				
Light troffer supply?				
Balanced within 3-5 years?				
Balanced after recent renovations?				
Short circuiting or other air distribution problems? Note location(s) ____________________ ______________________________				
Pressurized Ceiling Supply Plenum				
No unintentional openings?				
All ceiling tiles in place?				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ____________________

Completed by: ____________________ Title: __________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Barrier paper correctly placed and in good condition?				
Proper layout for air distribution?				
Supply diffusers open?				
Supply diffusers balanced?				
Noticeable flow of air?				
Short circuiting or other air distribution problems? *Note location(s) in"Comments"*				
Terminal Equipment (supply)				
Housing interiors clean and unobstructed?				
Controls working?				
Delivering rated volume?				
Balanced within 3-5 years?				
Filters in place?				
Condensate pans clean, drain freely?				
VAV Box				
Minimum stops ________ %				
Minimum outside air ____ % *(from page 2 of this form)*				
Minimum airflow __________cfm				
Minimum outside air ______ cfm				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: ____________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Supply setpoint _____°F (summer) _____°F (winter)				
Thermostats				
Type ______________________				
Properly located?				
Working?				
Setpoints _____°F (summer) _____°F (winter)				
Space temperature _____°F				
Humidity Sensor				
Humidistat setpoints _______ % RH				
Dehumudistat setpoints _____ % RH				
Actual RH _____ %				
Room Partitions				
Gap allowing airflow at top?				
Gap allowing airflow at bottom?				
Supply, return each room?				

HVAC Checklist - Long Form

Building: ____ File Number: __________________________

Completed by: ____________________________ Title: ________________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Stairwells				
Doors close and latch?				
No openings allowing uncontrolled airflow?				
Clean, dry?				
No noticeable odors?				
Return Air Plenum				
Tiles in place?				
No unintentional openings?				
Return grilles?				
Balancing capability?				
Noticeable flow of air?				
Transfer grilles?				
Fire dampers open?				
Ducted Returns				
Balanced within 3-5 years?				
Unobstructed grilles?				
Unobstructed return air path?				
Return Fan Chambers				
Clean and no trash or storage?				
No standing water?				
Floor drain traps are wet or sealed?				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: ____________________ Date Checked: ________

Component	OK	Needs Attention	Not Applicable	Comments
No air leaks?				
Doors close tightly, kept closed?				
Return Fans				
Location ____________________				
Fan blades clean?				
Belt guards installed?				
Proper belt tension?				
Excess vibration?				
Corrosion problems?				
Controls working, calibrated?				
Controls sequence conforms to design/specifications? (describe changes)				
Exhaust Fans				
Central?				
Distributed (locations) __________ ____________________				
Operational?				
Controls operational?				
Toilet exhaust only?				
Gravity relief?				

HVAC Checklist - Long Form

Building: ____ File Number: _________________________

Completed by: ___________________________ Title: _______________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments
Total powered exhaust _____ cfm				
Make-up air sufficient?				
Toilet Exhausts				
Fans working occupied hours?				
Registers open, clear?				
Make-up air path adequate?				
Volume according to code?				
Floor drain traps wet or sealable?				
Bathrooms run slightly negative relative to building?				
Smoking Lounge Exhaust				
Room runs negative relative to building?				
Print Room Exhaust				
Room runs negative relative to building?				
Garage Ventilation				
Operates according to codes?				
Fans, controls, dampers all operate?				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: ____________________ Date Checked: ________

Component	OK	Needs Attention	Not Applicable	Comments
Garage slightly negative relative to building?				
Doors to building close tightly?				
Vestibule entrance to building from garage?				
Mechanical Rooms				
General condition?				
Controls operational?				
Pneumatic controls:				
■ compressor operational?				
■ air dryer operational?				
Electric contols?				
EMS (Energy Management System) or DDC (Direct Digital Control):				
■ operator on site?				
■ controlled off-site?				
■ are fans cycled "off" while building is occupied?				
■ is chiller reset to shed load?				
Preventive Maintenance				
Spare parts inventoried?				
Spare air filters?				
Control drawing posted?				

HVAC Checklist - Long Form

Building: ______________________________ File Number: ______________________

Completed by: ______________________ Title: ____________________ Date Checked: ________

Component	OK	Needs Attention	Not Applicable	Comments
PM (Preventive Maintenance) schedule available?				
PM followed?				
Boilers				
Flues, breeching tight?				
Purge cycle working?				
Door gaskets tight?				
Fuel system tight, no leaks?				
Combustion air: at least 1 square inch free area per 2000 Btu input?				
Cooling Tower				
Sump clean?				
No leaks, no overflow?				
Eliminators working, no carryover?				
No slime or algae?				
Biocide treatment working?				
Dirt separator working?				
Chillers				
No refrigerant leaks?				
Purge cycle normal?				
Waste oil, refrigerant properly disposed of and spare refrigerant properly stored?				
Condensation problems?				

HVAC Checklist - Long Form

Page ___ of ___

Building: ____ File Number: ___________________________

Completed by: ____________________________ Title: ________________________ Date Checked: __________

Component	OK	Needs Attention	Not Applicable	Comments

Pollutant Pathway Form For Investigations

Building Name: ____ File Number : ____________________________

Address: ____ Completed by: __________________________________

This form should be used in combination with a floor plan such as a fire evacuation plan.

Building areas that appear isolated from each other may be connected by airflow passages such as air distribution zones, utility tunnels or chases, party walls, spaces above suspended ceilings (whether or not those spaces are serving as air plenums), elevator shafts, and crawl spaces.

Describe the complaint area in the space below and mark it on your floor plan. Then list rooms or zones connected to the complaint area by airflow pathways. Use the form to record the direction of air flow between the complaint area and the connected rooms/zones, including the date and time. (Airflow patterns generally change overtime). Mark the floor plan with arrows or plus (+) and minus (-) signs to map out the airflow patterns you observe, using chemical smoke or a micromanometer. The "comments" column can be used to note pollutant sources that merit further attention.

Rooms or zones included in the complaint area: ____

____

Sections 2, 4 and 6 discuss pollutant pathways and driving forces.

Rooms or Zones Connected to the Complaint Area By Pathways	**Use**	**Pressure Relative to Complaint Area**		**Comments (e.g., potential pollutant sources)**
		+/-	**date/time**	

Pollutant and Source Inventory

Building Name: ____ Address: ____________________________________

Completed by: _____________________________________ Date: _______________ File Number: ___________________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Sections 2, 4 and 6 discuss pollutant sources. Appendix A provides guidance on common measurements.

Source Category	**Checked**	**Needs Attention**	**Location**	Comments
SOURCES OUTSIDE BUILDING				
Contaminated Ambient Air				
Pollen, dust				
Industrial contaminants				
General vehicular contaminants				
Emissions from Nearby Sources				
Vehicle exhaust (parking areas, loading docks, roads)				
Dumpsters				
Re-entrained exhaust				
Debris near outside air intake				
Soil Gas				
Radon				
Leaking underground tanks				
Sewage smells				
Pesticides				

Pollutant and Source Inventory

Building Name: ____ Address: ________________________________

Completed by: _________________________________ Date: ______________ File Number: _________________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Source Category	**Checked**	**Needs Attention**	**Location**	**Comments**
Moisture or Standing Water				
Rooftop				
Crawlspace				
EQUIPMENT				
HVAC System Equipment				
Combustion gases				
Dust, dirt, or microbial growth in ducts				
Microbial growth in drip pans, chillers, humidifiers				
Leaks of treated boiler water				
Non HVAC System Equipment				
Office equipment				
Supplies for equipment				
Labratory equipment				

Pollutant and Source Inventory

Building Name: ______________________________ Address: ______________________________

Completed by: ______________________________ Date: ____________ File Number: ______________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Source Category	Checked	Needs Attention	Location	Comments
HUMAN ACTIVITIES				
Personal Activities				
Smoking				
Cosmetics (odors)				
Housekeeping Activities				
Cleaning materials				
Cleaning procedures (e.g., dust from sweeping, vacuuming)				
Stored supplies				
Stored refuse				
Maintenance Activities				
Use of materials with volatile compunds (e.g., paint, caulk, adhesives)				
Stored supplies with volatile compounds				
Use of pesticides				

Pollutant and Source Inventory

Building Name: ____ Address: ____________________________________

Completed by: _____________________________________ Date: _______________ File Number: ___________________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Source Category	Checked	Needs Attention	Location	Comments
BUILDING COMPONENTS/FURNISHINGS				
Locations Associated with Dust or Fibers				
Dust-catching area (e.g., open shelving)				
Deteriorated furnishings				
Asbestos-containing materials				
Unsanitary Conditions/Water Damage				
Microbial growth in or on soiled or water-damaged furnishings				

Pollutant and Source Inventory

Building Name: ____ Address: ________________________________

Completed by: _________________________________ Date: ______________ File Number: _________________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Source Category	Checked	Needs Attention	Location	Comments
Chemicals Released From Building Components or Furnishings				
Volatile compounds				
OTHER SOURCES				
Accidental Events				
Spills (e.g., water, chemicals, beverages)				
Water leaks or flooding				
Fire damage				

Pollutant and Source Inventory

Building Name: ____ Address: ____________________________________

Completed by: _____________________________________ Date: _______________ File Number: ___________________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Source Category	Checked	Needs Attention	Location	Comments
Special Use/Mixed Use Areas				
Smoking lounges				
Food preparation areas				
Underground or attached parking garages				
Laboratories				
Print shops, art rooms				
Exercise rooms				
Beauty salons				
Redecorating/Repair/Remodeling				
Emissions from new furnishings				
Dust, fibers from demolition				
Odors, volatile compounds				

Pollutant and Source Inventory

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Building Name: ____ Address: ____________________________________

Completed by: _____________________________________ Date: _______________ File Number: ___________________

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment. Sources of contamination may be constant or intermittent or may be linked to single, unrepeated events. For intermittent sources, try to indicate the time of peak activity or contaminant production, including correlations with weather (e.g., wind direction).

Sections 2, 4 and 6 discuss pollutant sources. Appendix A provides guidance on common measurements.

Source Category	Checked	Needs Attention	Location	Comments

Chemical Inventory

Building Name: ____ File Number: ____________________________

Address: ____

Completed by: ____ Phone: __________________________________

The inventory should include chemicals stored or used in the building for cleaning, maintenance, operations, and pest control. If you have an MSDS (Material Safety Data Sheet) for the chemical, put a check mark in the right-hand column. If not, ask the chemical supplier to provide the MSDS, if one is available.

Sections 2 and 6 discuss pollutant sources. Section 4 discusses MSDSs.

Date	Chemical/Brand Name	Use	Storage Location(s)	MSDS on file?

Hypothesis Form

Building Name: ____ File Number: ____________________________

Address: ____

Completed by: ____

Complaint Area (may be revised as the investigation progresses):

____

____

____

____

Complaints (e.g., summarize patterns of timing, location, number of people affected):

____

____

HVAC: Does the ventilation system appear to provide adequate outdoor air, efficiently distributed to meet occupant needs in the complaint area? If not, what problems do you see?

____

____

Is there any apparent pattern connecting the location and timing of complaints with the HVAC system layout, condition or operating schedule?

____

____

Pathways: What pathways and driving forces connect the complaint area to locations of potential sources?

____

Are the flows opposite to those intended in the design? ____

Sources: What potential sources have been identified in the complaint area or in locations associated with the complaint area (connected by pathways)?

____

Is the pattern of complaints consistent with any of these sources? ____

Hypothesis Form

Hypothesis: Using the information you have gathered, what is your best explanation for the problem?

____

____

____

Hypothesis testing: How can this hypothesis be tested?

____

____

____

____

____

If measurements have been taken, are the measurement results consistent with this hypothesis?

____

____

____

Results of Hypothesis Testing:

____

____

____

____

Additional Information Needed:

____

____

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