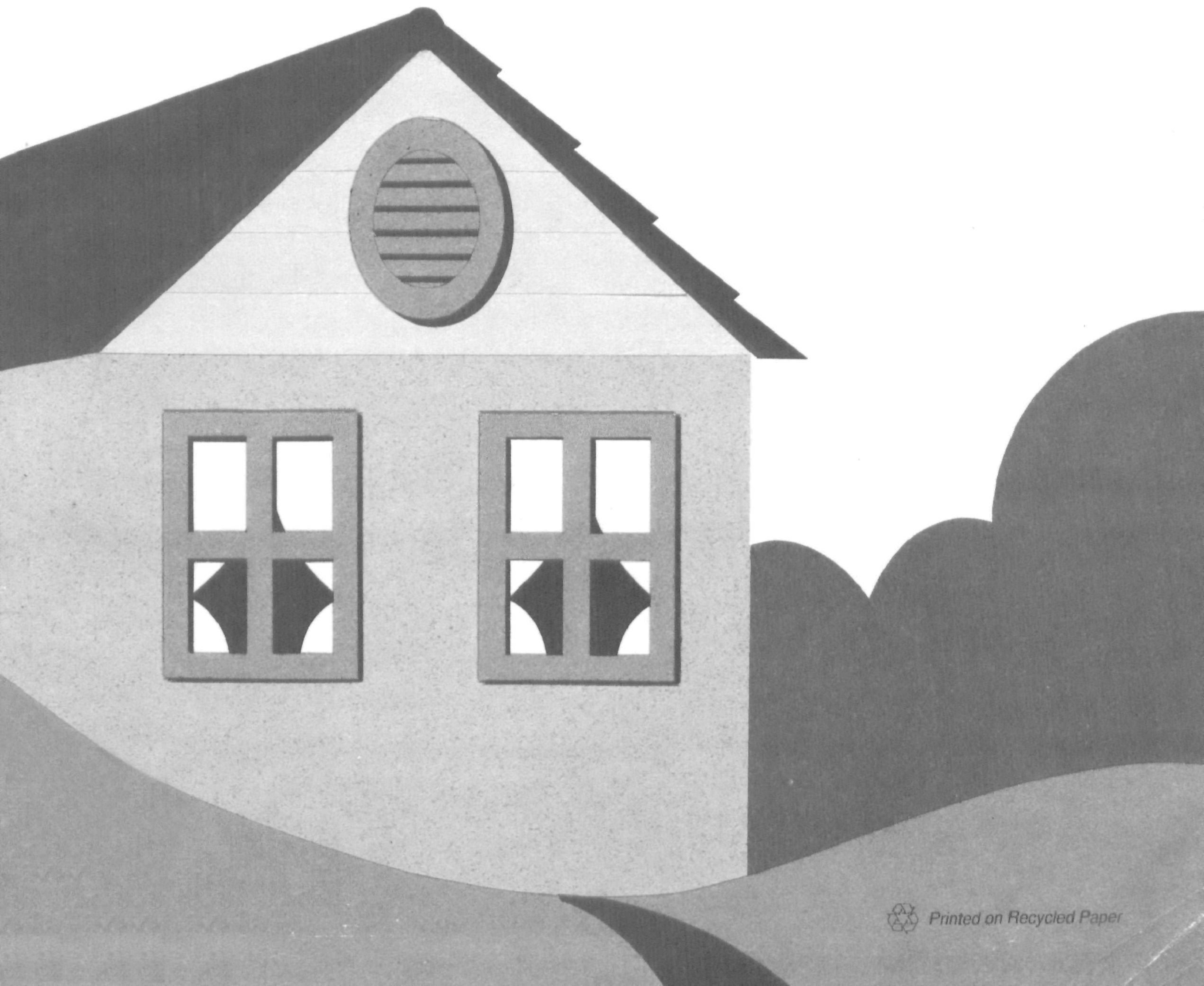
United States Environmental Protection Agency
United States Public Health Service
National Environmental Health Association
EPA/400/3-91/002
July 1991
Office of Air and Radiation (ANR-445W)

Introduction to Indoor Air Quality

A Self-Paced Learning Module



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FOREWORD

The *Indoor Air Quality Learning Module* and its companion document, the *Indoor Air Quality Reference Manual* were produced under a cooperative arrangement between the National Environmental Health Association, the U.S. Public Health Service, and the U.S. Environmental Protection Agency. The documents are designed to provide an introduction to indoor air quality for environmental health professionals. The documents cover those aspects of indoor air quality important for establishing and implementing an indoor air quality program by a state or local governmental agency.

Because there is substantial guidance already available from EPA on radon and asbestos, the *Learning Module* and the *Reference Manual* contain little information on these subjects. In addition, while most of the information presented is useful for all types of indoor environments, the primary focus for both documents is on residential indoor air quality.

ACKNOWLEDGEMENTS

The *Indoor Air Quality Learning Module* and the *Indoor Air Quality Reference Manual* were developed under a cooperative arrangement between the National Environmental Health Association, the Bureau of Health Professions of the U.S. Public Health Service, and the Indoor Air Division of the Environmental Protection Agency.

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The following persons are gratefully acknowledged for their contributions:

Barry Stern had the foresight to recognize the importance of indoor air quality issues and the need to strengthen the competency of practicing environmental health professionals in this area. His initiative in developing this project, his support, and his patience have been fundamental to the success of this work.

David Mudarri was the principal technical advisor for this project. He provided expert technical guidance and made extensive and invaluable editorial contributions. His insight and thoughtful assistance provided the framework for both documents, and his tireless effort and encouragement helped steer the project through many difficult times.

Edward Culver (Bureau Administrator, Bureau of Environmental Health, Health and Hospital Corporation of Marion County, Indianapolis, Indiana) contributed Lesson 9 of the *Learning Module*, "Establishing an Indoor Air Quality Program."

Geraldine Struensee spent many hours typing complex tables and initially formatting the documents. Her forbearance through innumerable revisions is sincerely appreciated.

Reviewing Organizations

Individuals from the following organizations reviewed and commented on all or part of the two documents.

Federal Agencies

Bonneville Power Administration,
  Department of Energy
Consumer Product Safety Commission
Department of Health and Human Services
  National Institute of Environmental Health Sciences
  National Institute for Occupational Safety and Health
  Department of Housing and Urban Development
    Office of Policy Development and Research
Environmental Protection Agency
  Office of Air and Radiation
  Office of Pesticides and Toxic Substances
  Office of Research and Development
  Office of Water
General Services Administration
  Public Buildings Services

State and Local Government Agencies

Association of Local Air Pollution Control Officials, Washington, DC
Central District Health Department, Boise, ID
Clark County Health Department, Las Vegas, NV
Connecticut Department of Health Services, Hartford, CT
Division of Environmental Services, Toledo, OH
Forsyth County Environment Affairs Department, Winston-Salem, NC
Health and Hospital Corporation of Marion County, Indianapolis, IN
Illinois Department of Public Health, Springfield, IL
Lincoln-Lancaster County Air Pollution Control Agency, Lincoln, NE
Mansfield Health Department, Mansfield, MA
Maryland Department of Education, Baltimore, MD

(continued next page)

Minneapolis Department of Environmental Health, Minneapolis, MN
Montgomery County Public Schools, Rockville, MD
Plano Health Department, Plano, TX
Southeastern Health District, Pocatello, ID
State College Health Department, State College, PA

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INTRODUCTION

OVERVIEW OF THE MODULE

Indoor air quality is a topic of increasing concern to environmental health professionals. Most people spend over 90% of their time indoors, and for some contaminants, exposure to indoor air poses a potentially greater health threat than outdoor air exposures.

The last 15 years have been punctuated by concern over several specific indoor air contaminants including formaldehyde, radon, asbestos, and environmental tobacco smoke. Emerging concerns include exposure to combustion contaminants, microorganisms, pesticides, volatile organic compounds, and mixtures of contaminants. In addition, it is becoming more evident that many indoor air quality problems are inextricably linked to indoor climatic conditions including temperature, humidity, and rates of ventilation.

The purpose of this module is to introduce environmental health professionals to the information needed to recognize, evaluate, and control indoor air quality problems. A *Reference Manual*, which can be used as a reference guide and a vehicle for continuing education, has been developed as a companion document to this module. The *Reference Manual* contains more detailed information about topics related to the *Learning Module*. Mastery of the information in the *Reference Manual* will provide the practitioner with a strong foundation for understanding specific contaminants, sources, measurement and interpretation of data, control methods, and investigation techniques.

The *Learning Module* approaches the broad topic of indoor air quality by developing an understanding of the general principles needed to recognize, diagnose, mitigate, and prevent indoor air quality problems. Unit 1 provides an historical perspective on indoor air quality, presents background information on the factors which influence indoor air quality, lays the foundation for evaluating health effects from indoor air contaminants, and discusses general principles for controlling the indoor air environment. Unit 2 discusses general principles of measuring indoor air contaminants, identifies standards and guidelines for ventilation and air contaminants, and describes techniques which can be used to investigate indoor air quality problems. Finally, Unit 3 provides the basic background needed to establish an indoor air quality program.

MODULE OBJECTIVES

After you complete this module, you will be able to:

- **understand and identify the sources and factors that affect indoor air quality;**
- **discuss health effects and symptoms in terms of classes of contaminants and recognize the limitations of solving problems based on health effects alone;**
- **discuss principles of measuring indoor air contaminants;**
- **identify general and specific methods of controlling indoor air quality;**
- **identify the types of standards and guidelines which are available to assist in the interpretation of indoor air quality data and recognize the limitations of each;**
- **understand the basic principles for conducting an indoor air quality investigation and interacting with clients; and**
- **understand the basic administrative requirements for establishing an indoor air quality program.**

The *Reference* Manual is divided into eight sections, corresponding to the first eight lessons of the *Learning Module.* If more detailed information is needed on a particular subject, the reader can easily find the relevant portion of the *Reference Manual* that pertains to that subject. Frequent references to the *Reference Manual* are also included within the text of the *Learning Module.* In addition, to further assist in locating information, parenthetical notations in smaller typeface, which refer the reader to the relevant sections in the *Reference Manual*, are occasionally included next to section headings in the *Learning Module.*

The material in the *Learning Module* (and the *Reference Manual*) is directed primarily to residential structures, but nonresidential buildings, including schools, office buildings, and public buildings are also addressed. EPA is developing guidance documents for the investigation and control of indoor air quality in nonresidential buildings.

HOW TO USE THIS MODULE

Each lesson in the module begins with learning objectives that are the focus of the lesson, and closes with a progress check that contains questions about the material in the lesson. The progress checks give you a measure of your understanding of the material contained in the lesson. You should complete each progress check before starting the next lesson. Answers to the progress checks can be found within the text.

Be sure to review the lesson before going to the next one if you answer any of the questions incorrectly.

A final examination covering the material contained in the lessons can be found at the end of the module. If you wish to receive a certificate that acknowledges your mastery of the material in the module, complete the examination as instructed. The National Environmental Health Association (NEHA) will score the examination and issue a certificate to you if you complete the examination with an acceptable score.

SECTION 1.
OVERVIEW OF THE REFERENCE MANUAL

The *Indoor Air Quality Reference Manual* is the companion document to the *Indoor Air Quality Learning Module.* The purpose of the *Reference Manual* is to provide an opportunity for continuing education plus useful reference material on selected indoor air quality topics.

The *Reference Manual* is divided into 8 sections corresponding to the first eight lessons of the *Learning Module.* Section 1 provides an overview of the *Reference Manual* and suggests ways that the *Reference Manual* can best be used as an adjunct to the *Learning Module.* Sections 2-8 contain information that supplements the corresponding lessons in the *Learning Module.* For example, Lesson 2 of the *Learning Module* describes the factors that affect indoor air quality, while Section 2 of the *Reference Manual* shows how those factors are combined in indoor air quality modeling to simulate indoor environments; Section 2 also provides specific information and data on individual factors. Sections 3 and 4 of the *Reference Manual* correspond to Lessons 3 and 4 of the *Learning Module* and contain information on the nature of human responses as well as health effects from specific contaminants. Section 5 contains information about air cleaning devices and residential heating and air mover systems.

The *Reference Manual* also contains information and exhibits which can be directly used in field investigations. For example, Section 4 contains tables which relate symptoms, contaminants, and sources in a way that could assist in diagnosing indoor air quality problems; Section 6 provides information on specific measurement techniques and equipment, including availability of equipment from various manufacturers; Section 7 provides a listing of public health and occupational standards which can be useful in interpreting measured data; and Section 8 includes specific forms and questionnaires which can be used to collect data during field investigations.

CONTAMINATION OF INDOOR AIR

Dissatisfaction with the quality of indoor air is not new. Problems probably date to the time when early man and woman discovered the use of fire and were exposed to the products of incomplete combustion. Mummified lungs from the pre-industrial age show considerable carbonaceous pigmentation, and these people were probably also exposed to carbon monoxide.

Early evidence of exposure to indoor air contaminants and efforts to control them comes from the placement of fires in caves and the presence of vent holes in the roofs of caves. It is also demonstrated by the way in which ancient native people in the United States constructed noncave dwellings. This can clearly be seen in the ruins of early settlements in such locations as Mesa Verde, Colorado and Chaco Canyon, New Mexico.

In modern times, the use of synthetic building materials and fabrics has become commonplace. After World War II, traditional building materials such as wood were replaced with cheaper alternative materials that could be produced and processed on a large scale. New products such as plastics and pressed-wood products were introduced as materials for building construction and furnishings.

An explosion also occurred in the development of personal care products, pesticides, and household cleaners. Relatively simple and less toxic household cleansers such as baking soda, vinegar, soap, and lye solutions were replaced by more sophisticated chemical formulations. These consumer products were increasingly packaged in convenient aerosol cans which released their contents directly into the indoor air.

Most recently, the energy crisis of 1974 and the increase in the cost of oil from $3/barrel to $30/barrel focused concern on conserving energy in homes and other buildings. The desire to reduce heating and cooling costs led to changes in construction techniques in both residential and commercial buildings which reduced building ventilation rates. These changes included tighter building envelopes; fewer and inoperable windows; decreased use of operable windows in older construction; use of sealant foams and vapor barriers; reductions in the amount of outdoor air used for ventilation; improperly sized and designed heating, ventilating, and air-conditioning (HVAC) systems; renovations of existing buildings without corresponding changes to the HVAC systems; and inadequate building maintenance.

These changes have had two basic effects: an increase in the number and types of contaminants released into the indoor environment, and a decrease in the amount of fresh outdoor air that is introduced into structures to dilute contaminants and satisfy the health and comfort needs of occupants.

Now, the drafty, uninsulated home or office of the first part of the century has been replaced by a new structure that is tightly sealed by comparison. The introduction of outdoor air available to dilute indoor levels of contaminants has dropped from an estimated 1.5 air changes per hour (ach) to about 0.5 ach or lower in especially efficient residential construction.

Increased insulation in buildings and changes in acceptable operating temperatures increased energy efficiency, but also resulted in tight buildings which retained moisture and other contaminants and provided a more favorable environment for microbial growth. Decreases in the amount of outside replacement air led to "stuffy" environments that felt too damp and cold in winter and too warm and stuffy during the summer. Some people switched to auxiliary heating appliances such as unvented gas stoves and kerosene heaters to provide economical sources of heat. These appliances raised concerns about respiratory health effects and potential asphyxiation.

The use of biomass fuels (wood, crop residues, and dung) is an important source of contaminants worldwide. In developing countries about 30% of urban households and 90% of rural households use these fuels (Smith, 1987). It is estimated that about half of the world's households use biomass fuels as their principal source of energy for cooking. Most of the cooking is done indoors using unvented stoves. Indoor levels of contaminants (such as carbon monoxide, formaldehyde, respirable particulates--especially benzo(a)pyrene) have been shown to be considerably higher than outdoor levels in these countries (Smith, 1987).

HEALTH CONCERNS

Persons in the United States and Europe generally spend over 90% of their time indoors (U.S. EPA, 1989). This means that the quality of the air they breathe indoors is a dominant consideration in determining their overall exposure to air contaminants.

Overall, changes in construction techniques, ventilation rates, and the increased use of synthetic products have resulted in an increasing number of complaints about the quality of indoor air, both at home and in the workplace.

Knowledge about the relationship between exposure to indoor air contaminants and health has evolved more slowly than knowledge about outdoor air contaminants. Contact, including direct droplet spread, was accepted for many years as the only way in which contagious diseases were spread. This theory was challenged beginning around 1935, but even as late as 1946, a Committee to Evaluate the Effectiveness of Methods to Control Airborne Infection reported at the annual meeting of the American Public Health Association: "Conclusive evidence is not available at present that the airborne mode of transmission of infection is predominant for any particular disease" (Langmuir, 1980).

During the 1950s and 1960s it did become clear that diseases could be spread by the airborne transmission of microorganisms. This was demonstrated in a pivotal study by Riley *et al.* in 1959 in which it was shown that vented air from a tuberculosis ward contained droplet nuclei capable of infecting guinea pigs.

The ability to detect health effects and routes of transmission has become more sophisticated. Now, it is known that organisms causing diseases such as Legionnaires' disease can be incubated and distributed indoors under the right conditions. Also, it is known that a wide range of contaminants can be released into living spaces from building materials, furnishings, combustion appliances, and as a by-product of using various consumer and commercial products.

Beginning with the late 1940s, regulatory efforts focused on controlling outdoor air pollution because it was assumed to be the main source of exposure to air contaminants outside of the workplace. This was largely a consequence of serious air pollution problems that occurred in large urban areas throughout the world. In the United States, photochemical smog was recorded in Los Angeles in the 1940s, and the first "smokestack" episode occurred in Donora, Pennsylvania in 1948. This episode occurred when dust and fumes from steel mills and zinc smelters became trapped in a stagnant air mass over the community. Over 6000 people became ill and twenty died as a result of breathing the polluted air.

During the 1950s, 1960s, and early 1970s it was assumed that being indoors would provide protection from outdoor air pollution. Plans for emergency action during episodes of high air pollution were written to encourage susceptible individuals to remain indoors during days of high outdoor air pollution. It is now known that the quality of air indoors can be worse than outdoor air in some cases.

Beginning with the late 1960s and early 1970s, a series of issues drew public attention to the potential health effects associated with exposure to indoor air contaminants and focused scientific and government attention on the need for more research and programs in this area.

In the United States, the release of formaldehyde from urea-formaldehyde foam insulation (UFFI) and construction materials used in conventional and mobile homes was widely perceived as a major health threat reportedly related to effects ranging from odor complaints to respiratory tract irritation to cancer. Subsequently, asbestos and radon were recognized as major indoor air contaminants, and Federal programs were developed to deal specifically with these issues.

After the energy crisis, reports of discomfort effects and illness among people living and working in "tight," energy efficient buildings became widespread. The mysterious Legionnaires' disease outbreak in 1976 heightened concern about the incubation and transmission of microorganisms via HVAC systems.

Many of the advances in knowledge about health effects were the direct result of technical advances in the measurement of contaminants and exposures. The development of personal exposure monitors (PEMs) and measurement concepts involving a Total Exposure Assessment Methodology (TEAM) have contributed to the ability of scientists to evaluate indoor exposures as part of total environmental exposures. The TEAM studies and others have shown that indoor concentrations of some contaminants are often 2 to 5 times higher than outdoor concentrations, and the primary route of exposure for these contaminants is through the indoor air (Wallace, 1987).

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PROGRESS CHECK

1. Give three reasons why indoor air quality has become a serious problem in modern times. What are some of the differences in construction practices, ventilation rates, building materials and furnishings, and consumer products that affect indoor air quality?

2. What air quality issues were of concern before 1970? After 1970, what were some of the issues that focused attention on indoor air quality?

LESSON 2
FACTORS AFFECTING INDOOR AIR QUALITY

The quality of air indoors depends on many factors related to the structure, the outdoor environment, and the occupants. An understanding of how these factors affect indoor air quality is important to the successful prevention, diagnosis, and mitigation of problems.

LESSON OBJECTIVES

At the end of this lesson you will be able to:

- **identify and understand different factors that affect indoor air quality;**
- **list important sources of indoor air contaminants and identify some of the major contaminants of interest;**
- **understand the concept of air exchange rate and the factors that affect it; and**
- **understand the concept of infiltration and identify major sources of air leakage in residential structures.**

FACTORS AFFECTING INDOOR AIR QUALITY
(RM 2)

In general, the quality of the indoor air is a combination of physical stressors and the concentration of contaminants. Physical factors which include temperature, humidity, noise, and light are discussed in Lesson 4. The level of contaminants is determined by the net influence of those factors which emit, mix, and remove contaminants. These factors are introduced in this lesson, and may be classified into five broad categories: sources of contaminants, air exchange rates, contaminant removal mechanisms including chemical reactions, volume of the structure, and mixing efficiency of the indoor environment.

Table 2-1 summarizes some of the variables that influence these factors. The listed factors are used mainly in a qualitative way to evaluate contaminant problems. These factors can also be quantified to varying degrees and are used in predictive mathematical models to evaluate indoor air quality. Section 2 of the *Reference Manual* provides an overview of a basic model that quantifies the relationships among these factors.

Sources of Contaminants *(RM 2.2)*

Sources of contaminants that influence indoor air may be located in the interior or the exterior of the structure. Descriptions of example sources and source categories follow. Section 2 of the *Reference Manual* contains a more detailed list of sources and the individual contaminants which can be released by them.

The rate of contaminant release from a source is called the emission rate. Emission rates can vary considerably even for a single source and can be affected by changes in the operation of equipment and appliances (for example, combustion contaminants) or by changes in environmental conditions such as temperature and humidity (for example, formaldehyde emissions from building materials). Emission rates are used in mathematical models to calculate contaminant concentrations under a variety of conditions. Section 2 of the *Reference Manual* summarizes data on emission rates which have been determined for some contaminants.

Indoor Sources

Indoor sources of contaminants are important contributors to indoor air pollution. Major source categories include consumer and commercial products, building sources, and personal sources.

Consumer and commercial products: There are numerous consumer and commercial products which can result in the release of indoor air contaminants. These include cleaners and waxes, paints and associated supplies, pesticides, adhesives, cosmetics and personal care products, automotive products, hobby supplies, paper products and printed material, moth repellents and air fresheners, dry cleaned fabrics, and furnishings. Hundreds of inorganic and organic compounds can be released as a result of using these products. Examples include caustic aerosols and other particulates, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) such as alcohols, ketones, ethers, esters, aliphatic and aromatic hydrocarbons, and other substituted hydrocarbons.

In addition to the active or primary ingredients, containerized products may contain other ingredients which can also be hazardous. Carriers or solvents, propellants, dyes, curing agents, flame retardants, mineral spirits, plasticizers, odor-forming ingredients, hardeners, resins, binders, stabilizers, and preservatives are some of the other ingredients which may be hazardous and are contained in these products.

Aerosol products are of concern because the aerosol droplets which are produced are in the inhalable size range. These droplets can remain in the air for extended time periods providing a mechanism for inhalation exposure to occur to less volatile components of the product.

Table 2-1. Factors affecting indoor air quality and examples of the parameters which influence them.

	EXAMPLE PARAMETERS		
Factors	Outside Structure	Inside Structure	Related To Occupants
SOURCES	outdoor air geology water supply	building materials appliances furnishings	occupant density smoking use of combustion appliances and consumer products
AIR EXCHANGE	meteorology topography surrounding obstacles structure orientation season time of day	heating, ventilating, and air-conditioning (HVAC) systems temperature windows/doors insulation and weather-proofing	operation, maintenance, use patterns for natural and mechanical vent-ilation
CONTAMINANT REMOVAL	building envelope	surface area and materials local exhausts air filters/cleaners	operation and mainte-nance of air cleaning devices
VOLUME		building design	
MIXING EFFICIENCY		local exhaust fans location of vents building design	opened/closed doors furniture placement

Consumer use patterns and activities are also important in determining whether or not contaminants will be released by products or activities. Dry sanding or open-flame burning of lead-based paint can release lead; soldering can release lead and other metals. The use of solvents and pesticides in enclosed or poorly ventilated spaces can pose special hazards. The use of unvented heating appliances or improperly installed, operated, or maintained heating appliances can result in elevated levels of combustion contaminants indoors. Airborne pathogens and allergens can result from poor hygienic conditions, excess moisture, or water damaged materials. They can also become airborne when using vacuum cleaners.

Perhaps the most important source of indoor air contaminants is tobacco smoke which contains both organic and inorganic particles and gases; many of these contaminants are carcinogens or can promote the carcinogenic potential of other contaminants.

Building sources: Many different types of VOCs, including formaldehyde, can be released by building materials such as pressed wood products; glues and adhesives; sealants; insulating materials such as styrofoam, urethane, and urea formaldehyde foam insulation (UFFI); floor and wall coverings; plastics; and electrical equipment.

Airborne pathogens and allergens can thrive in a variety of building sources including wet or moist insulation, wood, walls, or ceilings. In addition, poorly maintained humidifiers, dehumidifiers, air conditioners, and heat recovery ventilators can also become sources of airborne pathogens and allergens.

If openings exist from the soil to the interior of the building, radon and other soil gases can migrate indoors. Occasionally, earth-derived building materials such as gypsum, brick, concrete, soil, or rock from some areas can serve as a source of radon.

Combustion contaminants such as carbon monoxide and the oxides of nitrogen can be released from leaking furnaces, chimneys, and flues; downdrafting from wood stoves and fireplaces; improper stoking of fires; gas cooking stoves; unvented kerosene and gas heaters; and automobile exhaust from attached garages. Polynuclear aromatic hydrocarbons (PAHs) can be released from the combustion of wood and coal.

The building can also be a source of particulates such as asbestos from poorly maintained or damaged insulating materials, lead from sanding lead-based paint, and other fibers and dusts.

Humans, plants, and pets: Humans, plants, and pets can be sources of allergens (such as dander), pathogenic viruses, and bacteria. Plants also can release allergenic spores into the air. Pets can be an additional source of pesticides (for example, contamination from flea powder and other pesticides). Also, small amounts of carbon monoxide, carbon dioxide, and a variety of VOCs such as acetone, acetic acid, alcohols, ketones, and aldehydes are released when human and pets respire.

Outdoor Sources

Contaminants in the air, soil, and water from outdoors can migrate indoors. Outdoor air, contaminated by emissions from industrial plants, motor vehicle exhaust, and residential heating units can result in both trace and elevated levels of a broad range of inorganic and organic particles and gases indoors. Emissions from soil and/or drinking water can result in elevated levels of radon gas, other radioactive contaminants, and VOCs indoors.

The composition of outdoor air varies from one location to another. The major constituents of outdoor air include nitrogen (78.1%) and oxygen (20.9%); minor constituents include the noble gases, methane, carbon dioxide, water vapor, and a variety of contaminants from both natural and man-made sources. Background concentrations of some of these contaminants are in the range of 300 parts per million (ppm) carbon dioxide, 0.02 ppm ozone, 0.1 ppm carbon monoxide, 0.003 ppm nitric oxide, and 0.001 ppm nitrogen dioxide (ASHRAE, 1985).

Concentrations of these contaminants in polluted air vary, but values that are 5 to 10 times higher than background levels have been measured in many locations.

The building's envelope (roof, walls, and windows) acts as a barrier to prevent outdoor air from entering the living space, but it does not provide a perfect seal and contaminants in the outdoor air enter the indoor environment through infiltration and natural ventilation. Whether or not outdoor air becomes a major contributor to indoor air pollution depends on outdoor contaminant concentrations, air exchange rates, and the extent to which the building envelope (shell) removes the contaminants.

Generally, as outdoor concentrations of contaminants increase, so do indoor air concentrations. This increase is at a slower rate and with a slight lag in time, but if the outdoor concentrations stay at a constant value, the indoor concentration could eventually be expected to reach that of the outdoors for most contaminants.

Outdoor air sources close to the building can dramatically influence indoor air quality. Contaminants from street traffic, outdoor pesticide applications, barbecue grills, trash storage areas, or similar sources can enter through open doors and windows or infiltrate through the building envelope.

In commercial buildings with mechanical ventilation systems, a major contributor to indoor air quality problems has been improperly located outdoor air intake vents. When intake vents are improperly located, contaminants from loading docks, parking areas, roofing tars, and other sources can enter through the intake vent and contaminate the indoor environment. Also, contaminants from building exhausts, including restroom exhausts, can reenter the building through the outdoor air intake vents when the exhaust and intake vents are located close to one another.

Geology and soil structure are important determinants of the potential contamination indoors by radon and other contaminants. Radon is perhaps the most widely known example of a gas that can migrate from the soil into a structure. Other gases and chemical liquids can also enter the living space from contaminated soils. For example, methane, carbon dioxide, and other gases can migrate from sanitary landfills into basements; contaminants from leaking storage tanks and hazardous waste sites can also migrate through the soil and enter interior spaces. The migration of these contaminants indoors can occur when building interiors are depressurized due to wind, by the operation of exhaust fans, or by an improperly balanced mechanical ventilation system.

In addition, water contaminated with organic chemicals or radon can release these contaminants to the inside air during showering, dishwashing, and similar activities.

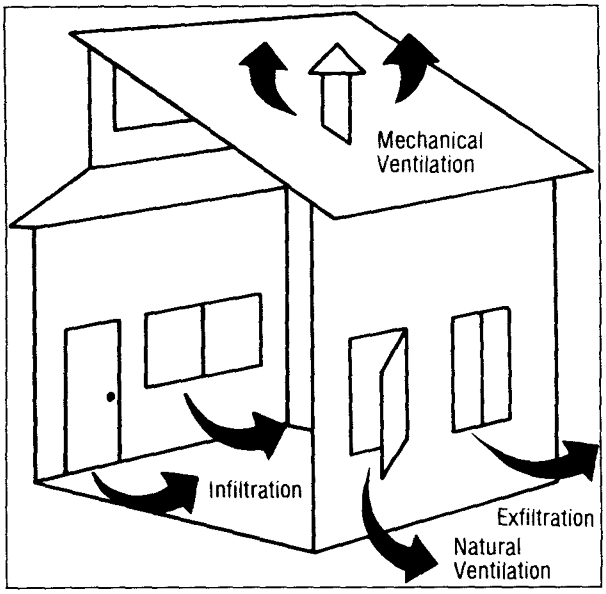
Air Exchange Rates *(RM 2.1)*

The air exchange rate is the rate at which indoor air is exchanged with outdoor air, and it is expressed as the number of times the air volume in a structure is exchanged with the outdoor air each hour. Air exchange in a structure occurs by infiltration, exfiltration, natural ventilation, and mechanical ventilation (Figure 2-1).

The air exchange rate has units of air changes per hour (ach). The nominal air exchange rate can be calculated as the rate at which outdoor air enters the structure (m^3/hr or ft^3/hr) divided by the volume of the structure (m^3 or ft^3).

Assuming that a house has a volume of 500 m^3, and 250 m^3 of outdoor air enters the house each hour to replace the same amount of indoor air, the nominal air exchange rate is 0.5 ach. In this example, air equal to one half the volume of the house is replaced by outdoor air every hour, and an exchange of air equal to the total volume of the house will occur every two hours if all conditions remain the same. This does not mean that every air molecule in the house will be exchanged every two hours. Air

Figure 2-1. Pathways of air exchange.



SOURCE: Adapted from Sandia National Laboratories (1982)

exchange is a complex process that depends on air movement patterns and other factors (Table 2-1). The specific molecules that are exchanged will depend on the combined effect of all of these factors.

Generally, the outdoor air serves to dilute indoor air contaminant levels. That is, for nonreactive contaminants, the difference between indoor and outdoor levels will generally be inversely proportional to the air exchange rate.

A wide range of air exchange rates (as low as 0.1 ach to over 3.5 ach) have been measured in residential structures (ASHRAE, 1985). Air exchange rates for newer construction are generally in the range of 0.5 ach, but they may be as low as 0.1 ach in superinsulated houses (Lenchek *et al.*, 1987). Median air exchange rates for older low income houses of about 0.9 ach have been reported (ASHRAE, 1985).

Air exchange rates in mechanically ventilated office buildings can vary significantly from their design values, and depend, in part, on the ventilation system design; its installation, maintenance, and operation; and the tightness of the building envelope. In a comprehensive study of 14 buildings covering a total of approximately 3000 measurements, Persily (1989) reports that the mean value in each building ranged from 0.29 ach to 1.73 ach while the median value ranged from 0.41 ach to 1.65 ach. The mean value for all buildings was 0.94 ach and the median was 0.89 ach.

Infiltration and Exfiltration

Infiltration and exfiltration refer to the uncontrolled leakage of air into or out of a structure, respectively, through cracks and other uncontrolled openings in the envelope of the building. The term infiltration is sometimes used to refer to both infiltration and exfiltration. Cracks formed as the structure settles; leaks around windows and doors; openings for pipes, wires, and ducts; electrical outlets and recessed light fixtures; baseboard moldings; and connections between structural components can all serve as avenues for air movement.

Infiltration and exfiltration result from pressure differences between indoor and outdoor environments. These pressure differences can be caused by wind, temperature differences including stack effects, or by the operation of flues, chimneys, or exhaust fans. Air infiltration and exfiltration can vary substantially as these factors change.

Wind effect: As the wind flows over a building, an area of positive pressure is created on the windward (facing into the wind) side and an area of lower pressure results on the leeward (facing away from the wind) side. Air is forced into the building on the windward side, which increases the internal pressure of the building and forces air out of the leeward side. The pressures on the other sides of the building can be negative or positive, depending on the shape of the building, obstructions to airflow, and the angle of the wind. Generally, infiltration will increase with wind speed, and it also depends on topography and obstacles surrounding the building. Structures that are protected from the wind will have reduced infiltration compared to those without protection, assuming all else is equal.

Stack effect: The stack effect results from the tendency of hot air to rise in a column within a room, up a stairwell in a multi-story building, or through a solar air shaft, stack, or vertical flue. During the winter, the differences between indoor and outdoor temperatures cause warm air to rise, creating a positive pressure which forces air through available openings in the top of the structure. At the same time, reduced air pressure at lower levels draws in colder air to replace the escaped air (Fig 2-2). The stack effect is greater in tall structures or when the difference between the inside and outside temperature is large.

During the summer, the flows may be reversed and are generally less dramatic because the temperature difference between the inside and outside of the structure is smaller.

Combustion effect: Air leakage can also be affected by wood stoves, fireplaces, and any other combustion heating systems. If indoor air is used for combustion, a negative pressure results inside, and room air that is exhausted through a flue or chimney is replaced by outdoor air. An operating fireplace, using indoor air for combustion, can nearly double the infiltration rate; using outside air for combustion does not have as significant an effect. A continuous stack effect can occur in chimneys or flues if the damper is open, or missing, even if the appliance is not operating.

When the stack or chimney effect is strong, infiltration increases. However, when the chimney or stack draft is weak, infiltration decreases and "backdrafts" can occur, pulling combustion products back into the living space.

Neutral pressure level: Because of the positive and negative pressure effects, some infiltration and exfiltration will occur in all structures. However, at some locations in the structure, the internal pressure will equal the external pressure. These points are called the neutral pressure level (NPL), neutral plane, or zero pressure point. The NPL depends on how easily air infiltrates or exfiltrates; it does not depend on how much air moves into or out of the structure (ASHRAE, 1989).

Above the NPL, the interior pressure is greater than the exterior pressure and air flows out of the structure. This is the normal case during the heating season. Below the NPL, the exterior pressure is greater than the interior pressure and air infiltrates more easily. The position of the NPL can be changed through the use of vents, dampers, and fans.

The location of the NPL has practical implications. For example, a high NPL ensures that airflow through the structure is in the form of infiltration, which, in turn, minimizes the likelihood of condensation in cold isolated cavities. However, if the NPL is located too high, backdrafting can occur.

Natural Ventilation

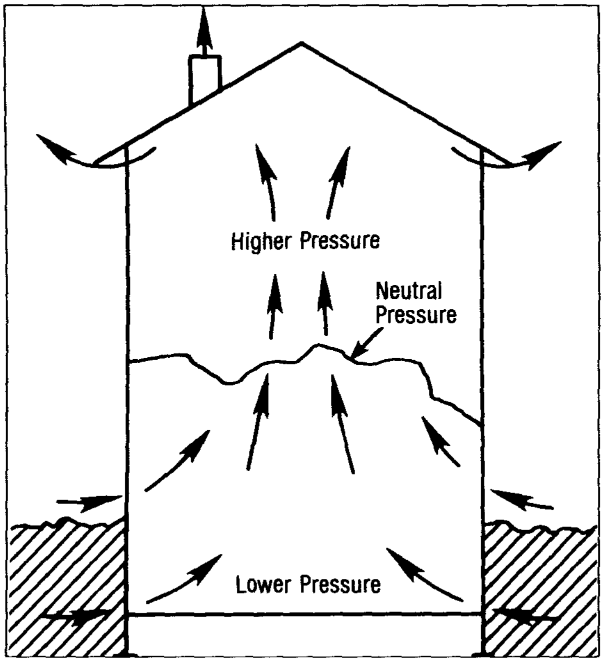
Natural ventilation is air that is supplied to the interior of a structure by windows, doors, or other openings that can be controlled. Natural ventilation occurs because of temperature and wind differences that cause air to flow through the openings.

Simple ventilation is a weak force that is driven by internal heating. It can be used to ventilate a single floor by allowing warmer air to exit through high openings and allowing fresh air to replace escaped air through lower openings. Cross ventilation is a strong force, driven by wind pressure, that moves air horizontally across one floor of a house. When a breeze blows, air flows into available openings on the upwind side and out of openings on the downwind side.

Mechanical or Forced Ventilation

Mechanical ventilation refers to supplying air by means of fans and ducts. These can be installed to

Figure 2-2. The stack effect.



SOURCE: Adapted from ASHRAE (1989); Mann (1989)

exhaust contaminants from localized areas (kitchen and bath) or to ventilate whole houses or structures.

The type and location of mechanical ventilation will affect contaminant concentrations. Local exhaust fans that are located in close proximity to a source (for example, range hood fans and bathroom fans) and exhausted outside can effectively remove contaminants. Exhaust fans must be properly sized to be effective, and they must be balanced by an air supply to prevent chimney backdrafting and to prevent unwanted infiltration.

In homes, mechanical (forced-air) systems are generally used to circulate conditioned air throughout the structure. In larger buildings, central ventilation systems are used not only to circulate air, but also to dilute contaminants by introducing outdoor air into the occupied spaces. As efforts have increased to make homes and offices more energy efficient, builders are reducing infiltration, and increasingly relying on mechanical ventilation systems to provide sufficient outdoor air to the interior of buildings. In order to operate efficiently and effectively, these systems must be properly designed, installed, operated, and maintained. In some instances, the mechanical system can become a source of contaminants such as microorganisms (from contaminated ducts and equipment), and VOCs (from adhesives and ducting material).

Contaminant Removal *(RM 2.1)*

Some contaminants can be removed by air cleaning devices, and some removal may also occur through chemical reactions and mechanical interactions between contaminants and surfaces inside the structure.

Filters and other air cleaning devices can remove gaseous and particulate contaminants; these methods and their effectiveness are discussed in greater detail in Lesson 5. Removal of particulates in residential and commercial environments by air cleaning devices is more feasible and has been more widely practiced than removal of gases. Proper installation, operation, and maintenance are critical to maximize the success of these devices.

Not all contaminants are removed in the same way. For example, carbon monoxide and carbon dioxide are unreactive with indoor surfaces and are removed primarily by air exchange. Some removal of nitrogen dioxide, sulfur dioxide, and formaldehyde, on the other hand, occurs through chemical reactions with surfaces. And, particles often settle out, attach to surfaces, or are removed by air cleaning devices.

The rates of chemical reactions with surfaces (for example, furnishings, wall and floor coverings) have not been thoroughly characterized for all contaminants, but the type of surface and the surface-to-volume ratio are important in determining removal rates. Removal rates have been calculated for some contaminants (see Section 2 of the *Reference Manual*), but they are subject to the same limitations as calculations of source emission rates. Rough textured walls and furnishings (carpet, upholstered furniture, curtains) are more effective in retaining particles than are smooth-textured surfaces. A large surface-to-volume ratio also favors removal of contaminants. These surfaces can also become sources if the contaminants are released back into the air at a later time.

Volume of the Structure *(RM 2.1)*

In general, as the available volume for contaminant dispersal increases, contaminant concentrations resulting from a given source decrease. For example, a kerosene heater operated for 2 hours in a 1000 ft^2 space with 0.5 ach would likely result in higher carbon monoxide concentrations than if the same heater were operated under identical conditions in a 2000 ft^2 space.

The entire volume of the house is not always available for contaminant dispersal. The extent to which the entire volume is used depends upon multiple factors including the configuration of the space, location of walls and other impediments to airflow, closed or partially closed doors that separate rooms, number of floors and circulation of air between floors, location of sources, thermal gradients, use of circulation fans and mixing of contaminants.

If a house has more than one floor, contaminant concentrations will likely be greatest on the floor that contains the source and the floors above that one due to thermal buoyancy, providing there is no mechanical mixing of the air. In a house with three levels, for example, radon concentrations generally will be greatest in the basement and lowest in the upper floor. If a fan is used to mix the air, the concentrations on the lowest level will likely decrease while the concentrations on the upper floor will likely increase. Concentrations on all floors will become more uniform as long as the fan is operating.

Mixing Efficiency *(RM 2.1)*

Mixing efficiency refers to the speed with which contaminants become dispersed throughout the interior space. Mixing efficiency depends on the volume of the interior space, the rate of air movement, and whether or not local exhausts are used. Mixing generally occurs at a faster rate in smaller spaces than in larger spaces. For smaller residences, complete mixing between rooms generally occurs within an hour or less, while complete mixing in larger homes may require more time.

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PROGRESS CHECK

1. What are the factors that affect the concentration of contaminants indoors?
2. Name five sources and one contaminant for each source that can be found indoors.
3. What is the air exchange rate and what variables affect it?
4. What is meant by infiltration and exfiltration?
5. What are some sources of air leakage into structures?
6. How does the stack effect affect air exchange?
7. How does the volume of the structure or mixing efficiency affect concentrations?

LESSON 3

HUMAN RESPONSE TO INDOOR AIR QUALITY: Principles of Toxicology

Many sources of indoor contaminants release hundreds, perhaps thousands, of chemical and biological agents into the air. These contaminants do not exist in isolation; they are present in complex mixtures which have been referred to as "chemical soups."

We are used to thinking in terms of people reacting adversely to individual contaminants, and much of our knowledge about toxicology follows from that framework. However, individuals can react adversely to cumulative or interactive indoor stresses which include mixtures of contaminants and the stresses from temperature, humidity, light, or noise conditions. Human reactions to these stressors can also be affected by psychological or social factors in the individual's environment. In addition, there are significant differences in individual sensitivities to various environmental parameters.

The purpose of this lesson is to help develop a broad framework for understanding and interpreting human response to indoor air quality contaminants and stressors.

LESSON OBJECTIVES

At the end of this lesson, you will be able to:

- **identify the general types of health and discomfort effects which can result from inadequate indoor air quality;**
- **identify methods used to study health effects;**
- **identify factors which affect potential health risks of contaminants;**
- **discuss the concepts of concentration, exposure, and dose; and**
- **identify susceptible subgroups of the population.**

TYPES OF ADVERSE RESPONSES TO INDOOR AIR QUALITY PROBLEMS *(RM 3)*

There is a continuum of human response from exposure to contaminants and environmental stressors that ranges from burdens which do not manifest physiologic changes, at one end of the spectrum, to mortality, at the other end. A wide variety of health effects between these two extremes has been associated with poor indoor air quality.

Classes of Effects

Human responses to contaminants and stressors can be categorized according to the type and degree of responses and the time frame in which they occur. These general classes of effects can apply to exposures in the occupational, outdoor air, and indoor air environments, and a single exposure can result in more than one effect.

Acute effects are those that occur immediately (usually within 24 hours) after exposure. For example, chemicals released from building materials may cause headaches or pollen may cause itchy eyes and runny noses in sensitive individuals shortly after exposure. Generally, acute effects are not long-lasting and usually disappear shortly after the exposure ends. However, some exposures (usually occupational or accidental exposures to high concentrations) can result in irreversible acute effects or even death.

Chronic effects are long-lasting responses to contaminants which are generally the result of frequently repeated exposures to concentrations (often low) over an extended period of time. The manifestation of effects is generally delayed rather than immediate. Emphysema which may be caused by smoking cigarettes is an example of a chronic effect which develops over time and fully manifests itself years after smoking begins. Cancer has been associated with exposure to contaminants such as asbestos, radon, environmental tobacco smoke, and organic chemicals such as benzene.

Subtle effects are those which are too small to be readily noticeable by the individual. For example, small changes in visual discrimination or pulmonary function can be measured in response to chemical exposures, but the person affected may not be able to discern these changes. The significance of some of these changes is not known.

Discomfort effects such as being too warm or too cold, typically result from climatic stressors such as temperature and the rate and direction of air flow. Mild irritation of the mucous membranes and respiratory tract has been associated with low humidities. Eye strain and headache have been related to light levels that are too low or bright.

Although the base of knowledge is expanding for identifying adverse health effects of indoor air contaminants, these effects are not fully known for all contaminants or mixtures of contaminants. This lack of dose-effect and exposure data can complicate the interpretation of data and the evaluation of individual indoor air quality problems.

Emerging Concerns

Contaminant Mixtures

Exposure to low-level contaminant mixtures is an issue of increasing interest. Contaminants do not exist in isolation, but as part of a complex and dynamic mixture which changes depending on time, human activities, and location. Contaminants in mixtures can have effects which are antagonistic, additive, or synergistic. Of particular interest are synergistic effects in which the combined effect is greater than the sum of the effects of the individual components. For example, the risk of getting lung cancer from exposure to asbestos *and* cigarette smoke is greater than it is from each risk added together. Antagonistic effects are those in which the combined effect is less than the sum of the effects from individual contaminants, and additive effects are those in which the combined effect is equal to the sum of the effects from individual contaminants.

Although the extent of chemical interactions in mixtures is not known, they may play an important role in causing the acute symptoms of various building associated health effects.

Building Associated Health Effects

Exposure to air inside buildings can result in specific diseases and a variety of health complaints that are primarily acute effects. These conditions are generally closely related in time to the individual's presence in the building. There is also concern that exposure to contaminants in building environments could result in possible chronic effects such as cancer and noncancerous respiratory diseases. Generally, distinctions are made between those building associated health effects which are clinically defined and for which a cause can be identified (building related illness) and those for which the cause is unclear (sick building syndrome).

Building related illness (BRI) refers to an illness brought on by exposure to building air when symptoms of illness, and clinical signs of pathology are identified, and an airborne agent and pathway for the agent are recognized. The causative agent can be chemical; frequently, however, the agent is a pathogen or a biological allergen. Typical sources of biological agents include contaminated humidifiers, cooling towers, cooling coils, drain pans or filters, and water-damaged building materials or furnishings.

Symptoms may be specific or mimic more general symptoms typical of the flu, including fever, chills, and cough; and serious lung and respiratory diseases may occur. Legionnaires' disease, hypersensitivity pneumonitis, and humidifier fever are examples of building related illness.

Sick building syndrome (SBS) refers to a series of acute, nonspecific complaints which occur in high prevalence among building occupants. SBS may also be referred to as tight or closed building syndrome. Typically, these symptoms are associated with being in the building and are relieved when the individual leaves; but for some individuals, symptoms may not subside on leaving the offending environment. Symptoms typically include irritation of the eyes, nose and throat; sensation of dryness in the mucosa and skin; erythema (reddening of the skin), mental fatigue; headache; runny nose; asthma-like symptoms; and odor complaints. Sensory irritation normally dominates the symptoms.

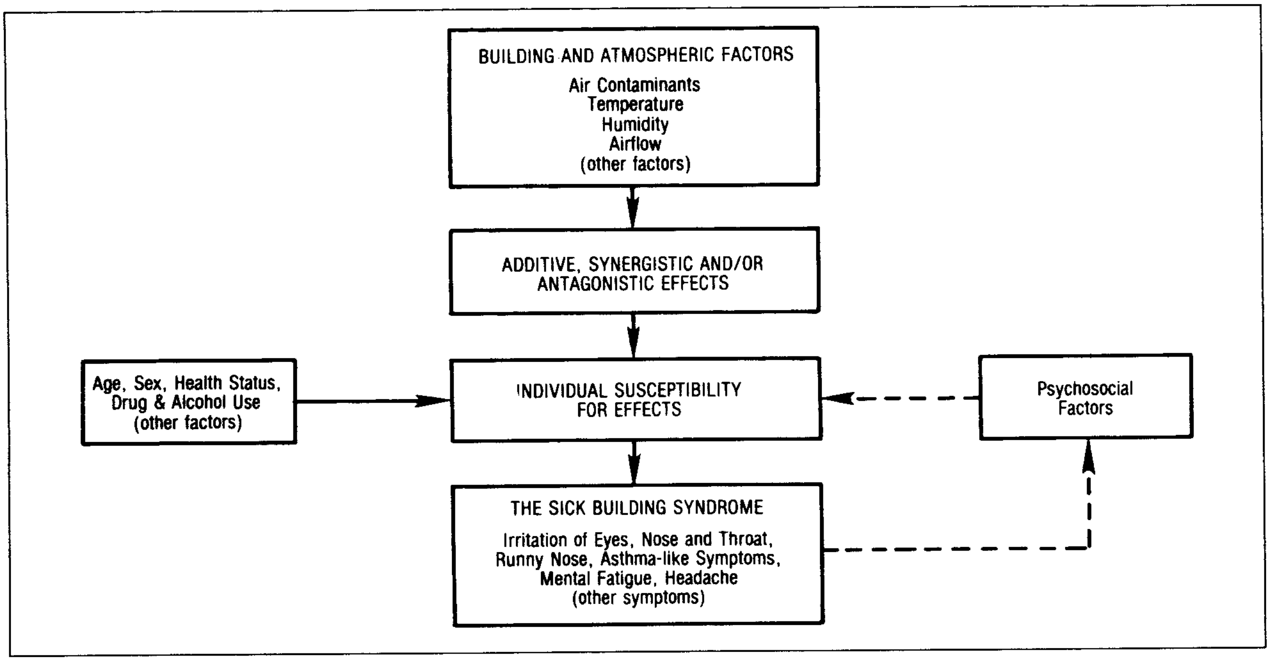
SBS probably does not cause death or life-shortening disease, but it does contribute to increased absenteeism, reduced work efficiency, discomfort, and irritation (WHO, 1986).

Unlike building related illness, a specific etiology for SBS is not known, and it is characterized by minimal physical signs and an absence of clinical abnormalities (laboratory studies, including spirometry and x-rays, are normal). Investigators are seldom able to identify any single exposure factor which exceeds a generally acceptable health threshold; as a consequence, specific causative agents are seldom identified. The causality, therefore, is often assumed to be multifactorial involving the combined effects of environmental and other stressors (Mølhave, 1985; Berglund and Lindvall, 1986). A general model reflecting this hypothesis is presented in Figure 3-1.

In this model, building and climatic factors can operate additively, synergistically, or antagonistically to affect the exposed individual. Buildings at highest risk appear to be new or recently remodeled buildings with tight envelopes, especially those with large ventilation systems that depend on limited fresh air sources (WHO, 1986). Improper ventilation, thermal conditions, and occupant lack of control over climatic and working conditions are other factors that may increase the likelihood of a building being linked to sick building syndrome.

Atopic individuals with a history or findings consistent with allergic rhinitis or asthma seem to

Figure 3-1. Multifactorial model for sick building syndrome.



SOURCE: Adapted from *Indoor Air and Human Health*, by R.B. Gammage and S.W. Kaye. Copyright 1985, Lewis Publishers, Inc., Chelsea, MI. Used with permission.

be at higher risk. An affected individual may respond with a number of symptoms that vary in intensity depending on the effect of other factors such as age, personal habits, and health status. In addition, psychosocial factors can contribute to SBS, and they can enhance or minimize the attention given to certain symptoms. However, the presence of a psychosocial feedback loop in Figure 3-1 should not be interpreted to mean that SBS is solely a psychological problem.

Mass Psychogenic Illness

A controversial syndrome that has been reported in some nonresidential investigations is mass psychogenic illness (less satisfactorily known as mass hysteria, mass conversion reaction, hysterical contagion, or epidemic psychogenic illness). This syndrome has been defined as a group of symptoms that develop in a group of individuals in the same indoor environment who are under some type of physical or emotional stress. It should be noted that the term mass psychogenic illness does not mean that individuals have a psychiatric disorder or that they are imagining symptoms.

There are concerns about labeling indoor air investigations as psychogenic illness when no cause can be found for reported problems. This diagnosis should be made carefully after thorough investigation and testing for suspected contaminants and stressors, and preferably, in consultation with an expert in psychogenic illnesses and a medical epidemiologist (Kreiss and Hodgson, 1984). It is important to note that the diagnosis should not be made solely on the basis of excluding physical, chemical, and biological agents (Kreiss and Hodgson, 1984).

It is hypothesized that a trigger such as unexplained or unpleasant odor, stuffy air, or low levels of respiratory irritants cause a physical reaction in a susceptible population. This population is assumed to have been stressed for a period of time by low-level chemical exposures, physical conditions, workplace stresses, or other factors (Colligan and Murphy, 1979; Colligan, 1981). The individual perceives the trigger to be threatening, the autonomic system is aroused, and physical complaints and symptoms result. These complaints and concerns are thought to spread quickly throughout the workplace.

The diagnosis of mass psychogenic illness is suggested by symptoms that do not have an organic basis or are inconsistent with exposure to any suspected contaminants. Another important component of the diagnosis is that individuals usually do not become ill unless they see or hear that others are becoming ill (Fischbein, 1990).

Mass psychogenic illness has been reported to occur among workers in low-paying stressful jobs that often involve boring and repetitive work, an unrealistic pace, rigid authoritarian organizations, lack of social supports, and physical stresses from noise and poor lighting (Colligan and Smith, 1978).

Multiple Chemical Sensitivity

It is well recognized that individual sensitivities to chemical and biological agents in air, water, and food can vary significantly, and that some persons may be hypersensitive to particular agents at levels which do not generate an observable response from the general population. It is also recognized that certain chemicals may be sensitizers, and once an individual becomes sensitized to a relatively high dose of a contaminant, the individual may be sensitive to much lower subsequent doses.

In addition to these specific sensitivity issues, there is a body of anecdotal evidence which suggests that some subset of the population may be especially sensitive to a broad range of chemicals at levels common in today's home and working environments. This potential condition has come to be known as multiple chemical sensitivity (MCS) (Cullen, 1987). Reported symptoms include vague feelings of not being well, joint and muscle aches and pains, recurrent respiratory infections, food intolerances, recent memory loss, and many others.

There is significant professional disagreement concerning whether MCS actually exists and what the underlying etiology might be. The concept of MCS was developed and is supported by physicians known as clinical ecologists. Although there are some areas of agreement between clinical ecologists (some of whom are also board certified allergists) and traditional allergists, there are disagreements about the levels of exposure that are necessary to cause health effects, what symptoms or diseases are associated with specific chemical exposures, and what mechanisms come into play (Ashford and Miller, 1989).

Based on their review of the literature and personal interviews with medical practitioners, Ashford and Miller (1989) conclude that there is sufficient collective evidence (anecdotal and scientific studies) to present a compelling case for MCS that warrants further study. Other reviews have not found convincing evidence to support the concepts underlying clinical ecology or its methods of diagnosis and treatment (American College of Physicians, 1989; Kahn and Letz, 1989).

Different hypotheses have been formulated in an attempt to explain this apparent phenomenon. These include, for example, a "spreading" phenomenon in which sensitization to one chemical spreads to other, often unrelated chemicals; a process of adaptation or addiction to chemicals involving overlapping stimulatory and withdrawal effects; and a total load concept in which the human body becomes overloaded with environmental (and possibly other) stressors (Asford and Miller, 1989). Psychiatric disorders have also been suggested as an explanation for reported symptoms (Black, Rathe, and Goldstein, 1990).

SCIENTIFIC BASIS FOR IDENTIFYING ADVERSE HEALTH EFFECTS *(RM 3.3)*

Information about the health effects of exposure to contaminants and physical stressors may come from several sources. These include animal data from controlled exposure studies and human data from accidental exposures, occupational studies, controlled human exposure studies, and epidemiological studies. Ideally, health effects guidelines or standards should be derived from studies that represent contaminant concentrations and exposure conditions that approximate the actual exposures experienced by the general population. However, the data base for the health effects of contaminants and physical stressors is generally limited, in part, because of the expense and inherent problems associated with studies of health effects.

Animal Exposure Studies

Animal exposure studies are generally based on large doses of contaminants administered over the relatively short lifetime of the animal (typically, a rat, mouse, or rabbit, but also other mammals, including dogs and monkeys). Standardized protocols which ensure highly controlled conditions are used. These studies usually involve 50 animals of each sex (for two species) treated at 2 to 3 different doses over the life expectancy of the animal (about 2 to 3 years for rats and mice). A control group is also required. Chemicals are administered by inhalation, ingestion, injection, or dermal applications. Relatively high doses are used to increase the sensitivity of the study. At the end of the exposure period, the animals are evaluated for effects, and the data are analyzed using statistical techniques.

The evaluation of animal data is difficult because the test animals may not reflect the human experience accurately. For example, target organs may be different, and humans and animals may not be equally sensitive to chemical exposures.

Nonthreshold effects (typically, carcinogens) must be extrapolated down to the lower concentrations that are usually experienced in occupational and nonoccupational exposures. The mathematical models used for these extrapolations can provide results that may vary over several orders of magnitude for a single toxic substance. In spite of these uncertainties, animal studies do provide good evidence of the carcinogenic potential of toxic substances in humans.

Results for observed threshold effects in animals are not extrapolated to low doses in humans. These results may be extrapolated across species by dose, followed by the application of an uncertainty factor to obtain a level at which effects are not observed [no-observed-adverse-effect level (NOAEL)]. There is also concern in these evaluations about the adequacy of the animal model.

Accidental Human Exposures

Accidental exposures such as those experienced in disasters at Chernobyl, Russia (radiation), Seveso, Italy (dioxin), and others have provided additional information about the acute and chronic effects of contaminants at relatively high exposures. Because these exposures are uncontrolled and it can be difficult, if not impossible, to reconstruct doses, these data usually provide only anecdotal support and are usually not used to develop guidelines, standards, or risk assessments.

Controlled Human Exposure Studies

Controlled human exposure studies are conducted under strictly controlled conditions in a laboratory. Subjects are exposed for generally short time periods to low levels of various contaminants. These studies are useful because dose-effect relationships at low concentrations can be evaluated. Limitations of these studies include the narrow populations studied (small number of healthy adults or those with mild disease are usually studied); the most hazardous chemicals cannot be studied for ethical reasons; and studies are generally limited to short exposure times.

Epidemiologic Studies

Epidemiology is the study of the distributions and determinants of health- and disease-related conditions in human populations. In an epidemiologic study, the investigator observes the occurrence of disease in people who are segregated into groups on the basis of a common experience or exposure. Epidemiologic studies can be used to associate health effects with the personal characteristics of those who are affected, the places where they live, work, or travel, and the time when effects occur. Analytic techniques can be used to determine the risk factors associated with a health effect.

Epidemiologic studies of indoor air quality may involve asking participants a variety of questions about products used, health status, and personal habits, and may attempt to evaluate exposures through the use of personal or fixed-site monitoring.

Limitations of epidemiologic studies include the expense of conducting studies which require large study populations in order to observe effects; difficulty in determining exposure rates; and the difficulty of identifying and quantifying factors (for example, occupation and smoking) which may also account for observed effects.

While laboratory studies can establish the causal association of a factor with a health effect more conclusively than epidemiologic studies, epidemiologic studies have provided and continue to provide a major contribution to our understanding of many diseases.

One source of controversy that has emerged from exposure studies is the interpretation of statistically significant results. A study of a large population can yield statistically significant results which cannot easily be interpreted biologically, and effects that are biologically important may not be statistically significant if the sample size is too small. As Samet (1985) comments, epidemiologic studies (and animal studies) describe the risks of groups, but not of specific persons, and other types of data may be needed to characterize susceptible persons and their responses to contaminants.

Risk Assessment Studies

Epidemiologic, animal, and human exposure studies provide the basis of risk assessments which may be used to determine policy. Risk assessments are estimates of the health impacts on the general population or specific subpopulations as a result of exposure to contaminants. Risk assessments can be conducted for both carcinogenic and noncarcinogenic effects, but most of the emphasis has been on carcinogenic effects.

EPA has published guidelines for exposure assessments and for evaluating risks from carcinogens, mutagens, teratogens, and chemical mixtures (U.S. EPA, 1986a-e). A four-step process begins with *hazard identification,* which is a review of the scientific literature to determine whether or not a contaminant may pose a human hazard. The second step, *dose-response assessment*, is the process of characterizing the relationship between health effects and specific doses of the contaminant. *Exposure assessment*, the third step, is the process of measuring or modeling the intensity, frequency, and duration of human exposure to the contaminant. The last step, *risk characterization*, is the process of combining the previous three steps to quantitatively estimate the risk and identify the uncertainties involved in the assessment. Section 3 of the *Reference Manual* discusses the process of risk assessment in greater detail.

FACTORS AFFECTING POTENTIAL HEALTH RISKS FROM CONTAMINANTS *(RM 3.1, 3.2)*

The potential health effects that will result from exposure to indoor air contaminants depend on a variety of factors interacting with one another. These include factors related to the toxic substance, the dose, the environment, and the occupant (Table 3-1).

Factors Related to the Toxic Substance

Toxicity is the innate ability of a contaminant to cause injury to biological tissue. The toxicity posed by natural and synthetic chemicals varies depending on the contaminant's chemical and physical properties and how those properties interact with the human body.

Two additional terms, hazard and risk, are sometimes confused with toxicity. Hazard describes a situation which may result in a health effect. Risk is the likelihood or probability that the health effect will occur in a specific exposure situation.

Solubility is simply the ability of one substance to dissolve in another substance. Chemicals can be classified as those that are soluble in polar solvents and those that are soluble in nonpolar solvents. From a health standpoint this difference is important. Chemicals which are polar in nature (such as table salt) will be more easily excreted from the body; chemicals which are nonpolar (such as PCBs and DDT) will not readily be excreted and will remain in the body for long periods of time.

Vapor pressure is a term that describes how readily liquids and solids vaporize or evaporate into the air. Vapor pressure is important because those chemicals having a high vapor pressure (for example, methylene chloride in paint strippers and toluene in paints) will be more likely to be inhaled than those with a low vapor pressure (for example, hydrocarbons in solid floor waxes).

Chemical structure is one of the most important characteristics of natural and synthetic chemicals which determines toxicity. The body has receptor molecules that recognize and react to chemicals as helpful to the body or as harmful intruders. For example, when a banana is eaten, the carbohydrates are recognized as helpful, and they are broken down and used for fuel in the body. On the other hand, the presence of harmful bacteria in the body initiates a different set of reactions aimed at destroying the intruders and ridding the body of them.

The body has the ability to discriminate among very subtle differences in chemical structure. For example, two chemicals that have exactly the same type and number of elements may have very differ-

Table 3-1. Key factors affecting the hazard posed by toxic substances.

Factors Related to the Toxic Substance:

Chemical Properties
Physical Properties
Toxicity

Factors Related to the Dose:

Concentration
Duration of exposure
Route of entry

Factors Related to the Environment:

Temperature
Humidity
Light and noise levels
Pressure differences
Presence of other contaminants

Factors Related to the Occupant:

Genetics
Sex
Personal habits
Diet
Age
Health status

ent effects on the body simply because of the location of the elements in relation to the overall structure of the chemical.

Size and *shape* are important physical properties of particles. Submicron-sized particles are more likely to be inhaled deep into the respiratory tract. The toxicity of asbestos is thought to be due to both its size and needlelike shape.

Factors Related to the Dose

The body's response to toxic substances (contaminants) depends in large part on the dose. The dose is the total amount of contaminant that is received by the target tissues. It depends on the concentration, the duration of the exposure, and on the route of entry.

Concentration, Exposure, and Dose

Dose should not be confused with the terms exposure or concentration. Concentration is the amount of contaminant that is present in the air at a given time and place. Exposure characterizes the contact between the contaminant and the person (skin, eyes, respiratory tract). The exposure will depend on both the concentration of the contaminant in a space and the length of time the person is in contact with the contaminant in that space. Dose is the amount of contaminant that is actually absorbed by the body. In many studies and assessments of risk, concentration is used as a surrogate for exposure or dose because the actual exposure or dose is difficult, and sometimes impossible, to measure.

In general, as the concentration of contaminants in the air increases, the exposure, dose, and effects also increase. People who are exposed to identical concentrations of contaminants, however, can receive different doses. For example, the dose of ozone received by a person who is sitting in a park on a hot day in Los Angeles will be different from the dose received by a person who is jogging in the park. The jogger receives a greater dose of ozone than the person who is sitting because the jogger is breathing faster and more deeply, causing more ozone to be in contact with the cells of the respiratory tract.

Route of Exposure

Contaminants can enter the body through ingestion, skin puncture, absorption through the skin, and inhalation. Except for inhalation, these routes of exposure are generally unimportant in residential or office indoor air quality problems. Inhalation is the most important route of exposure for airborne contaminants because chemicals are quickly and rapidly absorbed from the lungs into the bloodstream, where they can be carried to other parts of the body.

Absorption through the skin can be an important route of entry for certain organic substances. Some substances can be absorbed through hair follicles, and others dissolve in the fats and oils of the skin (for example, organic pesticides and solvent compounds). Ingestion could become an important route of entry if improper fumigation with pesticides resulted in contaminated food or dishes.

Dose-Effect Relationship

The relationship between the dose and its effect on the body is known as the dose-effect relationship, and it can be represented graphically (Figure 3-2). Small doses (characterized by low concentrations, short exposure times, and low respiration rates) usually cause minimal or no observable effects. As the dose increases (higher concentrations, longer exposure times, higher respiration rates) progressively more severe effects occur, which may include death at the highest doses. It should be noted, however, that a group of individuals who receive an identical dose of contaminant, might not respond uniformly because of human variability.

Attempts to relate health effects to exposure to air contaminants are rooted in dose-effect curves, and these curves are important tools in developing public policy for chemicals and other toxic agents in the environment. Two basic dose-effect curves are used to describe the relationship between effects and the dose.

Curve A in Figure 3-2 shows that no matter how low the dose, an effect will occur. This curve is called the linear dose-effect curve, and it is used to describe the carcinogenic effect of exposure to carcinogens such as asbestos and radiation.

Curve B describes a contaminant that will not cause an effect below a certain dose. This curve shows that there is a threshold for the occurrence of effects. For example, the lowest-observed-effect level for decreased hemoglobin production and central nervous system effects as a result of lead exposure in children is reported to be 0.1-0.2 micrograms of lead per milliliter of blood (WHO, 1987). In adults, the lowest-observed-effect level (for decreased hemoglobin production) is in the range of 0.15-0.3 micrograms of lead per milliliter of blood.

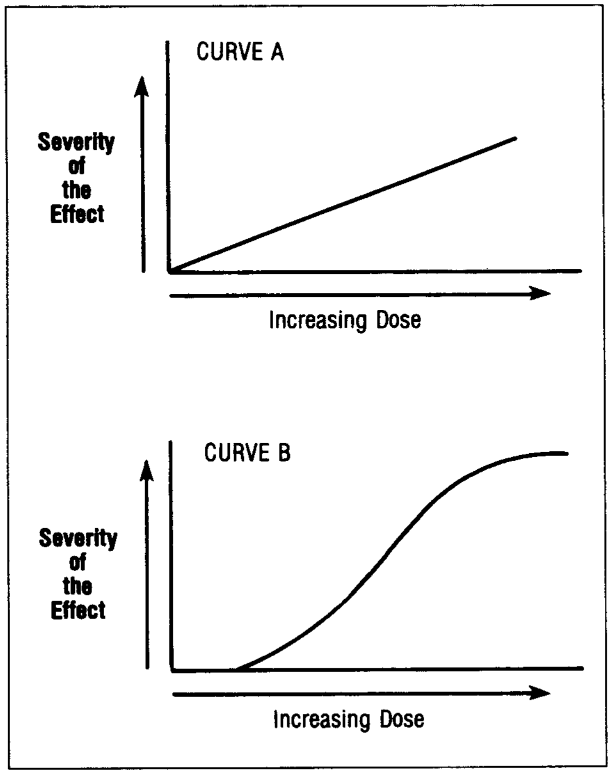
In the standard-setting process, the dose-effect curve is important because it, along with exposure assessments, determines what levels of contaminants are assumed to pose potential health risks.

Factors Related to the Environment

Environmental factors such as temperature, humidity, light, and noise levels can have direct and indirect effects on the host. These factors can affect the host directly by causing discomfort (for example, eye strain or headache) or even dysfunction (such as hearing loss). These factors may also affect the susceptibility of the occupant to other environmental contaminants or factors.

Temperature, humidity, and light alter the chemical nature of some contaminants which can make them more hazardous. In addition, high temperature and humidity can increase the rate of volatilization of organic chemicals such as formaldehyde. High humidity can foster the growth of microorganisms or increase the rate of chemical reactions which form acid aerosols. Reduced barometric pressure inside

Figure 3-2. Dose-effect relationships.



dwellings relative to the outside pressure can increase the rate of entry of radon (and other soil gases) into the interior environment.

Factors Related to the Occupant

The development of health effects in an individual who is exposed to chemical, physical, and biological stressors also depends on factors including genetics, sex, personal habits, diet, age, and health status. Table 3-2 identifies some of the subpopulations with potentially greater susceptibility to indoor air contaminants.

Genetic variability can range from individuals who have no disease resistance from birth to those who are seemingly never ill. Most people fall in between these extremes, but even in this middle area there can be significant variation in response to contaminants, particularly at the low level of exposures that might be encountered in homes and offices.

Men and women may also be affected differently by exposures to contaminants and other stressors because of their different chemical makeup. For example, men and women differ in the amount and distribution of body fat; this, in turn, may lead to a different distribution and accumulation of chemicals and subsequent toxic effects.

Personal habits such as smoking, alcohol intake, and other drug use can alter the body's ability to handle exposures to contaminants. Diet and psychological factors may also play an important role in determining the body's response to exposures. For example, individuals experiencing high stress levels may be more susceptible to the adverse effects of chemical exposure (Calabrese, 1978). In addition, stress may result in symptoms such as skin rash and anxiety which can appear to be chemically related.

Age is an important factor that affects sensitivity to contaminants. Infants and children are more sensitive to chemical exposures than adults. Their brains are not fully developed until they are about 6 to 7 years of age, and they may experience irreversible changes in learning ability or behavior if exposed to lead and mercury compounds. They are also more sensitive because they have smaller body size, faster breathing rates, immature immune and lung systems, and they are generally oral (mouth) breathers. Oral breathing circumvents some of the respiratory tract's defense mechanisms, resulting in larger doses to the remaining respiratory tract.

Older people may also be more sensitive to the effects of contaminant exposures because of the effects of aging on the immune system. The effects of aging and health status in response to chemicals were clearly illustrated during the serious air pollution episodes of the 1940s and 1950s. The people who were most affected and experienced the highest mortality were older people with preexisting heart and lung conditions.

In general, immunosuppressed individuals or those with chronic respiratory or cardiovascular diseases are more susceptible to the effects of indoor air contaminants, regardless of sex or age.

FATE OF CONTAMINANTS IN THE BODY

(RM 3.2)

After a contaminant enters the body it may be absorbed into the bloodstream, excreted unchanged, or transported throughout the body. Once it reaches the body's tissues it can be stored or interact with the body to produce toxic effects.

Metabolism is the process by which a chemical is changed in the body through the action of enzymes to form a new chemical called a metabolite. Metabolism, which occurs primarily in the liver and kidneys, generally is not 100% efficient, so some of the original chemical will remain. One of the main purposes of metabolism is to detoxify harmful chemicals by converting them into less harmful chemicals which can easily be excreted. Sometimes metabolites are formed which are more harmful than the original chemical.

After a chemical has been metabolized it may have the same fate in the body as the original chemical. It may be excreted or stored in the blood or other parts of the body. Nonpolar compounds (PCBs, chlordane, DDT) are stored primarily in the fat; metals such as lead and cadmium may be stored in bone, and others can be stored in the blood.

The kidney is the most important excretory organ in the body and it is able to excrete polar molecules such as alcohols, but it is less efficient with nonpolar molecules such as xylene. If a nonpolar metabolite is formed by the metabolism of a polar compound, the metabolite will be hard to excrete and may exert a toxic effect on the kidney. The original chemical or its metabolites can also be excreted through the feces, lungs, sweat, saliva, or breast milk.

The mechanisms by which toxic effects occur in the body have not been determined for all contaminants, and the process is not well understood for

Table 3-2. Subpopulations at greatest risk from exposure to indoor air contaminants.[1]

SUBPOPULATION	SIZE OF THE SUBPOPULATION	PERCENT OF POPULATION[2]
Newborns	3,731,000	1.5
Young children	18,128,000	7.5
Elderly	29,172,000	12.1
Heart patients	18,458,000	7.7
Persons with bronchitis	11,379,000	4.7
Persons with asthma	9,690,000	4.0
Persons with hay fever	21,702,000	9.0
Persons with emphysema	1,998,000	0.8
Smokers[3]	46, 772,500	26.5

SOURCE: Adapted from U.S. EPA (1989)

[1]All subpopulations except smokers are based on 1986 data. Data for live births, children < 5 yrs, and persons ≥ 65 yrs are based on U.S. Bureau of Census records. Data for persons with heart disease, bronchitis, asthma, hay fever, and emphysema are based on National Center for Health Statistics records.

[2]1986 national population of 241,078,000 was used for all categories except smokers.

[3]Persons ≥ 17 yrs of age who smoked in 1986; *Smoking and Health: A National Status Report.* 1990. U.S. Department of Health and Human Services (DHHS). DHHS (CDC) 87-8396.

many conditions. However, it does appear that the initial step of chemical exposures involves the recognition of the toxic chemical by a specific molecule(s) known as the receptor. The chemical binds itself to the receptor which initiates a chain reaction that may lead to an adverse health effect. As long as the receptor and the chemical are bound together, adverse effects can occur.

Over time, a balance is reached between bound and unbound receptors, and this balance can change as exposures increase or decrease. If a stored chemical is released, the potential for a toxic effect increases as the substance combines with receptors. For example, if a person who has been exposed to a nonpolar chemical such as PCBs loses weight, that chemical will be released into the bloodstream and adverse effects could result if the PCBs are not excreted.

The frequency of exposure also affects whether or not adverse effects occur. The body may be able to handle small exposures separated by long time periods during which the contaminant is metabolized and excreted. However, if the periods of time between exposures are shortened, adverse health effects may appear. For this reason, it is important to characterize exposures accurately.

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PROGRESS CHECK

1. Discuss some of the problems that can be encountered in trying to fit symptoms and health effects to indoor air contaminants.

2. What are the types of studies which provide information on health effects of indoor air contaminants?

3. What is the difference between chronic effects and acute effects?

4. What are the different factors that can affect potential health risks of contaminants?

5. What are important properties of gases and particles that determine their potential for health effects?

6. Discuss the concept of dose-effect relationships.

7. Which host factors can affect the risk posed by indoor air contaminants?

8. Briefly explain the differences between building related illness and sick building syndrome.

9. Briefly explain multiple chemical sensitivity and mass psychogenic illness. What are some concerns about these two emerging issues?

LESSON 4

HUMAN RESPONSE TO INDOOR AIR QUALITY: Classification of Indoor Air Contaminants

The complaints and health effects which might be related to building environments are sometimes similar to those from colds, flu, stress, and other causes. When the reported complaints are nonspecific and diverse, it can be difficult initially to determine if problems are caused by the sources or conditions in the building, and what can be done to remedy the complaints. A building investigation is performed in an effort to make these determinations.

In some instances, a specific source of contamination or a specific building condition causing the complaints is readily obvious. In the majority of cases, however, the investigator must consider all the factors that relate to indoor air quality (Lesson 2) to identify possible contaminants and stressors which could be responsible for the reported complaints and effects.

Because the process of relating symptoms and health effects to stressors and sources is complex, a multilevel approach is probably most likely to narrow the universe of possible causes of the problems. For example, the investigator may begin by formulating hypotheses about classes of contaminants or physical stressors based on the reported symptoms. These general classes of contaminants may then give rise to hypotheses concerning specific contaminants which are associated with specific sources in the building. At the same time, the investigator maintains an open mind about sources that may not be readily apparent and considers other causes, such as inadequate ventilation. Through a process of identifying and evaluating potential contaminants, sources and other factors, the causal factors can frequently be identified.

This lesson begins with an overview of the health effects and symptoms of general classes of toxic substances and physical stressors and closes with effects of specific contaminants.

LESSON OBJECTIVES

At the end of this lesson, you will be able to:

- **discuss classes of contaminants and physical stressors and symptoms related to these classes; and**
- **identify health effects related to specific contaminants.**

SYMPTOMS AND CLASSES OF TOXIC SUBSTANCES *(RM 3, 4)*

Symptoms do not always fit "textbook" patterns, and similar symptoms may be caused by different contaminants. In many instances reports of symptoms will include "low-level" complaints that are vague in nature and which could be attributed to any number of diseases or conditions. Very frequently, symptoms are characteristic of colds or the flu, or they are similar to symptoms accompanying stress and tension. Some examples of complaints include: "I feel tired and rundown." "I'm usually never sick, but now I have a lot of headaches." "I've been nauseated and have had a slight stomachache the last few months." "My nose always seems to be dry and my throat is scratchy."

Symptoms of different contaminants may also overlap. For example, formaldehyde can result in irritation of the upper respiratory tract and the eyes, but so can cleaning chemicals, airborne pathogens, airborne allergens, and some solvents. In order to sort through potential sources and interpret data, one may need to obtain a careful symptom history along with information about when and where symptoms occur. In doing this, the investigator should also be aware of contaminants that may not result in overt symptoms.

Indoor air contaminants can be classified by their mechanisms of action in the body and resulting symptoms. These categories are typically used for toxic substances and include irritants; asphyxiants; narcotics and anesthetics; systemic toxicants; reproductive and developmental toxicants; and airborne pathogens and allergens. Physical stressors such as temperature, humidity, light, and noise can also affect health. Symptoms which are commonly associated with these categories are summarized in Table 4-1.

Irritants

Irritants (including pulmonary toxicants) are highly reactive substances which result in nonspecific tissue damage when in contact with the body, particularly the skin and mucous membranes. Irritants such as formaldehyde, sulfur dioxide, nitrogen dioxide, ozone, petroleum-based chemicals, soaps, detergents, bleach, and other cleaning agents have been associated with a wide range of health effects. In addition, irritation effects can result from fibers such as fiberglass and other insulating materials; volatile organics from fabric cleaners, paints, and pesticides; disinfectants; oven cleaners; glues and epoxy resins.

The most common reactions include irritation of the eyes (redness and tearing), nose, throat, and upper respiratory tract. Upper respiratory tract symptoms typical of irritant contaminants are also very similar to irritation effects resulting from low humidity during the winter season and immunologic responses to airborne allergens.

Irritant chemicals can also result in acute and chronic skin irritation including dry, scaling skin; acne-like skin disease; pigment changes; and ulceration. Some are carcinogens. Dermatosis is a term that describes a skin disease from any cause. Noninflammatory dermatoses can be caused by excessive heat, low humidity, or sunlight interacting with some prescription drugs.

Dermatitis (acute or chronic; irritant or allergic) is a skin condition that has an inflammatory component. Examples include staph or strep infections caused by bacteria and exposure to biological allergens and chemicals. Epoxy resins, formaldehyde, metals, pharmaceutical drugs, plants, caustics, detergents, oils and greases, animal danders, saliva, and urine are some of the agents which can result in dermatitis. Usually, dermatitis is the result of direct contact with the agent; however, once an individual is sensitized by contact, the response can occasionally result from oral ingestion or even inhalation of the offending agent (Nethercott, 1990).

Table 4-1. Typical symptoms of contaminant classes and physical stressors.

SYMPTOMS	CONTAMINANT CLASSIFICATION: Irritant *(includes pulmonary toxicants)*	Asphyxiant	Anesthetic/ Narcotic	Systemic Toxicant	Airborne Pathogen/ Allergen	Carcinogen[a]	PHYSICAL STRESSORS: Temper- ature	Humidty	Light/ Noise
Eye Irritation, burning	✔							✔	
Dry or sore throat	✔							✔	
Skin irritation, dryness or scaling	✔							✔	
Skin rash				✔			✔		
Tightness in the chest	✔	✔			✔				
Runny nose	✔				✔				
Asthma *(exacerbation of)*	✔				✔		✔	✔	
Cough	✔			✔	✔				
Wheezing or other breathing problems	✔			✔	✔				
Chest pain	✔			✔	✔				
Changes in rate and depth of breathing		✔	✔	✔			✔		
Changes in pulse rate		✔	✔	✔			✔		
Visual disturbances		✔	✔						✔ (noise)
Dizziness		✔	✔				✔		
Fatigue		✔	✔	✔			✔		✔
Depression		✔		✔					✔
Clumsiness		✔	✔	✔					
Drowsiness		✔					✔		✔
Headache			✔		✔		✔		✔
Fever					✔				
Repeated throat infections					✔				
Sinus irritation or infection					✔				
Muscular pains					✔				
Change in heart rhythm				✔	✔				
Tingling or numbness in extremities				✔					
Muscle twitching/convulsions				✔					
Nausea or vomiting				✔					
Abdominal pain				✔					✔ (noise)
Diarrhea				✔					
Loss of appetite				✔	✔				
Cold/flu symptoms					✔		✔		
Cold extremities							✔		
Difficulty in sleeping					✔		✔		✔
Irritability									✔
Backache/neckache									✔
Eye strain									✔

[a]It is not possible to determine whether or not exposure to a carcinogen will result in a cancerous tumor based on symptoms because of the lag time between exposure and tumor development. However, carcinogens may also be classified as irritants, systemic toxicants, or anesthetic/narcotic, and may result in symptoms typical of these contaminant classes.

Pulmonary Toxicants

Acute and chronic exposure of the respiratory tract to irritants over a long period of time may be associated with increased susceptibility to bacterial infection, decreases in pulmonary function, changes in airway reactivity, and the development of lung diseases, including cancer.

Depending on particle size and the solubility of particles and gases, irritant contaminants can affect the upper or lower respiratory tract. Large particles and very soluble chemicals such as sulfur dioxide primarily affect the upper respiratory tract, while smaller particles and less soluble chemicals such as nitrogen dioxide and ozone affect primarily the middle and lower respiratory tract. Pulmonary toxicants also include airborne pathogens and allergens. Over time, pulmonary toxicants can contribute to the development of emphysema, bronchitis, pneumonitis, and changes in pulmonary function.

Emphysema (derived from the Greek, meaning bodily inflation) is a condition in which the air sacs in the lung become overinflated because the bronchioles that feed air into the air sacs become hypertrophied and lose their elasticity. This means that air can flow easily into the air sacs, but it cannot flow out because the bronchioles are too narrow. Because the person cannot exhale efficiently, the air remains in the air sacs. As air pressure builds up in the cells of the air sacs, the cells rupture and over time the air sac comes to resemble a balloon rather than a cluster of grapes. There is less surface area for gas exchange to take place and the individual becomes oxygen deficient. Emphysema is commonly associated with smoking and some occupational exposures to contaminants, and the main symptom is shortness of breath which is likely to become worse over a period of years.

Bronchitis is a condition in which the lining of the bronchi or bronchial tubes becomes inflamed. Acute bronchitis is usually caused when the same viruses that cause colds spread into the bronchi, but sudden increases in air pollution have also been implicated. Chronic bronchitis has been defined as a recurrent cough with phlegm production that occurs on most days during at least three months a year, usually in winter, for at least two consecutive years (Kung, 1982).

Bronchitis and other lower lung infections, particularly in children, have been associated with exposure to indoor air contaminants including environmental tobacco smoke, respirable particulates, nitrogen oxides, and sulfur dioxide. Chronic bronchitis ("smoker's cough") is typically caused by cigarette smoke.

Both acute and chronic bronchitis result in coughing and the production of phlegm. Other symptoms may include breathlessness, wheezing, fever, and pain in the upper chest which gets worse when the individual coughs. If chronic bronchitis is not treated, it can progress into either pneumonia, or over a longer period of time, emphysema.

Pneumonitis, alveolitis, and pneumonia are terms that refer to an inflammation of the lungs. These conditions are usually caused by exposure to physical agents (pneumonitis), microorganisms (pneumonia), and allergic reactions (alveolitis). The terms alveolitis and pneumonitis are sometimes used interchangably. Examples of causative agents include irritant gases and dusts, airborne bacteria and viruses, and airborne allergens such as mold, mites, and feathers. Symptoms of all three types include coughing, difficulty breathing (dyspnea), fever, chills, and muscle pains.

Chronic pneumonitis and alveolitis can result from repeated exposures to low levels of the agent or from recurrent acute episodes. Chronic symptoms include difficulty breathing, cough, fatigue, and weight loss; fever is uncommon. Repeated exposures to the agent can result in progressive lung scarring.

Changes in pulmonary function (lung volume and lung capacity) can also result from exposure to indoor contaminants such as environmental tobacco smoke, nitrogen oxides, and sulfur dioxide. (Section 3 of the *Reference Manual* defines some of the terms used in lung function testing). The significance of these changes, particularly relatively modest changes, has not been resolved. Changes in pulmonary function may or may not manifest themselves in symptoms such as breathing difficulties.

Asphyxiants

Asphyxiants are chemicals that interfere with the availability of oxygen for the tissues. A complete absence of oxygen in the blood (anoxia) will result in brain death in 3 to 5 minutes. Partial asphyxiation results in low levels of oxygen in the blood (hypoxia), and may result in brain damage or death, depending on the length of exposure. The normal oxygen level in the air is about 21%. Levels of oxygen in air below 19.5% are considered unsafe in the workplace [29 CFR 1910. 94 (d) (9)].

There are two classes of asphyxiants, simple and chemical, that differ in their mode of action. Simple asphyxiants are physiologically inert gases that act by diluting or displacing oxygen in air below the level required for normal function. Simple asphyxiants include carbon dioxide, nitric oxide, nitrous oxide, and nitrogen. Symptoms associated with exposure to levels of concern typically include drowsiness, headache, and changes in the rate and depth of respiration.

Chemical asphyxiants react chemically with the body to prevent the uptake of oxygen by blood or interfere with the transport of oxygen from the lungs to the tissues. Chemical asphyxiants include carbon monoxide, hydrogen sulfide, hydrogen cyanide, and others. Of these, carbon monoxide is the most likely to be encountered in indoor investigations. Typical sources in residential investigations include heating and cooking appliances as noted above, and in some instances, the ambient air or emissions from automobiles in attached garages.

In nonresidential investigations any combustion sources in the building or adjacent to air intakes should be evaluated. Effects from exposure to chemical asphyxiants can include the above symptoms plus depressed respiration, muscle spasms, visual disturbances, loss of appetite, impaired gait and balance, insomnia, weakness, and depression.

Narcotics and Anesthetics

Narcotics and anesthetics are chemicals that prevent the central nervous system from performing normally. Narcotic substances can result in symptoms that are similar to those caused by asphyxiants. Examples of narcotics and anesthetics include aliphatic ketones (methyl ethyl ketone, methyl isobutyl ketone, acetone), aliphatic alcohols (methanol, ethanol, isopropanol), and aromatic and substituted hydrocarbons (xylene, toluene, styrene, chlorobenzenes). Many of these chemicals are contained in paints, varnishes, pesticides, glues, and organic solvents that are commonly used in and around homes and in other nonindustrial settings.

Some of the anesthetic solvents can also result in cardiac sensitization. Inhalation of low levels of these compounds can make the heart very sensitive to certain chemicals (catecholamines) in the body, which in turn, can result in ventricular cardiac arrhythmias. There have been cases of cardiac sensitization reactions which resulted in the death of people who were working with solvents related to hobbies and crafts in poorly ventilated rooms. Caffeine and alcohol may enhance the ability of solvents to produce heart arrhythmias (Benowitz, 1990).

Systemic Toxicants

Systemic effects are those that occur after the distribution and absorption of the chemical at a site that is distant from the point of entry. The wide variety of ingredients in consumer products and in materials encountered in the nonindustrial environment can result in a range of systemic effects that is difficult to anticipate. Substances toxic to the liver (hepatotoxicants), kidney (nephrotoxicants), blood (hematopoietic toxicants), the nervous system (neurotoxicants), and the reproductive system can impair the functioning of these vital body systems.

Exposure of the kidney to chemicals can result in scarring of the filtering tissues which may ultimately lead to kidney failure. The liver has a crucial role in regulating the composition of the blood and also plays a role in other body processes. The central and peripheral nervous systems are also susceptible to damage from a wide range of toxic substances including metals (lead, arsenic, mercury), chlorinated hydrocarbons, volatile organic hydrocarbons, and various organic pesticides. Changes in fertility as a result of exposure to systemic toxicants have been documented for both men and women.

Acute or chronic exposures to chemicals which affect the body's systems can result in a wide range of symptoms that include fatigue, weakness, changes in blood pressure, changes in pulse rate, skin rash, sweating, depression, muscle twitching and convulsions, headache, tingling and numbness of the extremities, double vision, difficulty breathing, chest pain, wheezing, changes in respiration, coughing, vomiting, diarrhea, decrease in urinary output (oliguria), menstrual irregularities, muscle weakness, and others. Exposure to low concentrations may not result in immediate symptoms, but biochemical or structural effects can occur in the absence of symptoms.

Mutagens, Carcinogens, Developmental, and Reproductive Toxicants

Only a small fraction of the chemicals in commercial and consumer products have been tested for their potential as mutagens, carcinogens, and developmental or reproductive toxicants, and even less is known about mixtures of contaminants.

A mutagen is an agent that alters the genes or chromosomes of a living cell to cause mutations. Mutations can also occur spontaneously in the cell, and some are inherited. Cancer is thought to develop from a single cell that develops abnormally because of an alteration or mutation in the genetic material (DNA) which can occur spontaneously or after exposure to carcinogenic agents. Cancer usually develops years after exposure (7 to 40 years) to the agent.

Radon, asbestos, cigarette smoke, and formaldehyde are some of the agents in the indoor environment which have received attention for their carcinogenic potential. Symptoms of cancer typically do not occur until the tumor is already advanced.

Developmental toxicants are agents that cause some defect or malformation in the fetus; some defects may be so serious during the embryonic stage that a spontaneous abortion occurs. The fetus is most susceptible to the effects of developmental toxicants during the first three months of growth because this is a time of rapid cell growth and when organ systems begin to differentiate. Adverse effects, however, can occur throughout gestation.

Known human fetal toxicants include lead, alcohol, ionizing radiation, organic mercury, and some cancer-fighting drugs. Many more chemicals such as benzene; 2,4-D; nitrogen dioxide; PCBs; tetrachloroethylene; xylene; benzo(a)pyrene; phthalates; and others have been shown to be developmental toxicants in animal studies, but their effects on humans is not known (Rudolph and Forest, 1990).

Reproductive toxicants are agents that can result in menstrual disorders in women and decreased fertility in men and women. These agents typically are encountered through occupational exposures.

Pathogens and Allergens

Exposure to pathogens and allergens can result in a broad range of effects from mild irritation to life-threatening fevers and debilitating illness. These agents of illness can be particularly difficult to identify and relate to symptoms.

Airborne pathogens are infectious disease-producing agents such as viruses, fungi, and bacteria that are disseminated through the air. Common diseases that are spread by aeropathogens include influenza (virus), adenovirus and coxsackie respiratory diseases (virus), and coccidioidomycosis (fungus); other important diseases include Legionnaires' disease (bacterium), Pontiac fever (bacterium), and hypersensitivity pneumonitis (a variety of agents).

Allergens are substances that cause an allergic reaction in susceptible individuals. The allergic individual produces large amounts of an antibody when exposed to an allergen to which the individual is sensitive. When an antigen-antibody reaction takes place, histamine and other substances are released. Effects include dilation of blood vessels, mucus secretion, contraction of the bronchioles, and cellular inflammation.

Physical Stressors

Physical stressors such as temperature, humidity, light levels, and noise can result in a variety of symptoms which usually produce discomfort. More severe symptoms and dysfunction, however, can result if physical stressors are not corrected within reasonable periods of time.

Thermal Environment

A comfortable thermal environment is a function of many variables including temperature, humidity, air movement, activity level, clothing, and cultural practices and habits. It should be noted that guidelines can provide ranges of temperature, humidity, and air movement that will be perceived to be comfortable by most, but not all, people. Further, comfort ranges developed for the United States may not be valid for other countries where practices are different.

Temperature conditions affect the human organism in several ways. The temperature of the body is normally in the range of about 97.7°F to 99.5°F. When room temperatures are too cool, the body reacts by shivering and vasoconstriction (narrowing of the blood vessels). Vasodilation (widening of the blood vessels) and sweating occur in warm environments. Both of these reactions to warm or cool temperatures are perceived as uncomfortable, and individuals may react with complaints. Complaints about stuffiness are more likely to occur in rooms that are too warm, and complaints about drafts are more likely to occur in rooms that are too cool.

In the United States, most sedentary or slightly active people who are in a room with slow air movement will probably be comfortable at temperatures in the range of 68°F to 75°F during the winter and in the range of 73°F to 79°F during the summer (ASHRAE, 1981). It should be noted that infants, some elderly people, and those whose movements are confined may require temperatures at the upper end of the range or higher for comfort. The ASHRAE guidelines for thermal comfort also recommend vertical temperature differences of not more than 5°F from a level of 4 to 67 inches from the floor.

Humidity is the amount of water vapor within a given space, and it is commonly measured as the relative humidity (RH). Relative humidity is defined as the percentage of moisture in the air relative to the amount it could hold if saturated at the same temperature. Humidity in the air has both direct and indirect effects of people. Low relative humidity (dry air) can dry the mucous membranes and irritate the eyes, nose, and throat. Dry air can also exacerbate respiratory infections and increase problems with allergic and asthmatic symptoms. Air that is too humid feels oppressive, especially if combined with higher temperatures. Relative humidities less than 30% and greater than 70% are perceived as uncomfortable by many people. Relative humidity above 50% can enhance microbiological growth.

Air movement will also affect perceptions of comfort. Air movement less than 30 feet per minute (fpm) in the winter and less than 50 fpm in the summer is recommended (ASHRAE, 1981). If temperatures are less than optimum in the winter, it is important to maintain low air movements to minimize discomfort from local drafts. In the summer, increased air movement is desirable to extend the comfort zone.

Lighting should be free of glare, reflections, flickers, contrasts, and it should have the proper spectral distribution. The human eye can adjust to a very large range of light intensity, but symptoms can result depending on the light source and if the levels are too low or too high. When fluorescent lamps are used as the predominant source of light, many people describe the light as annoying, vibrating, or glaring; and they may develop eyestrain, fatigue, headaches, and other symptoms.

The importance of proper lighting for good health has been underscored in recent years with the discovery of cases of winter depression in areas that have a lack of natural light. This condition, which is manifested by a broad range of symptoms including fatigue, headache, and depression, can be cured through the use of lamps with the proper spectral distribution at home and the workplace.

In homes, artificial light levels of 6 footcandles over the area of a room at a height of 30 inches above the floor are considered adequate (CABO, 1989). In commercial buildings, proper lighting requirements vary with the activity or task to be performed. Illumination levels of 75 to 100 footcandles have been recommended for offices (IES, 1981). A major complaint of VDT operators is glare and/or contrast problems. These can result in significant complaints even if lighting levels are adequate, and added measures may be needed to reduce glare and/or contrast problems (Smith, 1984).

Noise is considered by some medical practitioners to be one of the most significant stressors of modern times. Noise can contribute to tension, fatigue, hearing loss, deficiencies in attention span, ulcers, high blood pressure, and heart disease. Sound levels are measured by a relative scale. The preferred unit for measuring sound in industrial, speech interference, and community disturbance conditions is the A-weighted decibel. The A-weighting delineates a frequency weighting scale which simulates the way in which the human ear actually responds to sound. The decibel scale is logarithmic, and the entire range of audible sound pressure for individuals with normal hearing can be expressed on a scale of 0 (the threshold of hearing) to 140 dBA (deafening and painful noise).

Levels below 40 dBA are considered to be comfortable. The average residence without a stereo playing will have a noise level of about 30 dBA, while noise levels in an average office will be about 50 dBA (U.S. HUD, 1985). The hearing of most people will probably be degraded by continuous exposure to levels above 85 dBA (U.S. HUD, 1985). It has been estimated that nearly half of the U.S. population is regularly exposed to noise levels that interfere with normal activities and 1 in 10 people may be exposed to noise levels that are sufficient to cause a permanent reduction in their ability to hear.

The U.S. Department of Housing and Urban Development (HUD) has developed exterior noise standards for new housing construction that is assisted or supported by the Department (U.S. HUD, 1985). HUD's regulations do not contain standards for interior noise levels, but the exterior standard should ensure that noise levels indoors do not exceed HUD's goal of 45 dBA for interior spaces.

EFFECTS OF SELECTED CONTAMINANTS *(RM 4)*

The previous section classified indoor air contaminants and stressors according to broad classes and health effects which might typically be associated with those classes. This section provides a summary of specific effects associated with selected contaminants. When the terms high and low concentrations are used they refer to concentrations that could be found in occupational and nonoccupational environments, respectively. The actual concentration ranges which have been associated with specific effects can be found in Section 4 of the *Reference Manual*.

Volatile Organic Compounds (VOCs) including Formaldehyde

VOCs are compounds which volatilize readily; VOCs include aromatic hydrocarbons, halogenated hydrocarbons, alcohols, ketones, aldehydes, ethers, esters, and others; several hundred VOCs have been identified in indoor air (U.S. EPA, 1989).

VOCs can result in eye, nose, and throat irritation; headaches; loss of coordination; loss of memory; nausea; and damage to the liver, kidney, and nervous system. Some organic gases cause cardiac sensitization reactions, and some are also known or suspected of causing cancer in humans. Exposure to mixtures of VOCs commonly found in building materials may be an important source of sick building complaints. In general, however, the health effects of exposure to VOCs through indoor air are not well understood.

Formaldehyde, which is probably the best known VOC, is often implicated as a cause of many indoor air quality complaints. It is an irritant. Eye, nose, and throat irritation, as well as symptoms including headache, wheezing, coughing, fatigue, and skin irritation may be experienced at the concentrations encountered in nonoccupational environments. Formaldehyde is also a known skin sensitizer. It has been shown to cause cancer and mutations in laboratory animal studies, and EPA has classified it as a "Probable Human Carcinogen."

Pesticides

Pesticides include both organic and inorganic chemically-based products which are used to kill household and garden pests including weeds, insects, termites, and rodents. Although there are data gaps for many pesticides, the EPA is in the process of accelerated re-registration of currently registered pesticides.

Severe acute exposures are generally easy to determine because a history of exposure is usually available and the symptoms are marked. Exposure to high enough levels can result in damage to the central nervous system, eyes, skin, heart, respiratory tract, kidneys, and liver. Symptoms could include headache, dizziness, blurred vision, skin rashes and sores, apprehension, confusion, bizarre behavior, convulsions, depression, loss of consciousness, pulmonary edema, heart arrhythmias, muscle weakness, paralysis, and others.

Chronic exposures can result in a variety of effects including central nervous system dysfunction (problems with memory, mood, fatigue), liver damage (abdominal pain, weight loss, vomiting, jaundice), tingling and numbness in the extremeties, kidney damage (difficulty urinating, incontinence), weakness, and other problems. The cancer-causing potential of some pesticide chemicals is also of concern.

Mild acute intoxication or subacute poisoning is more difficult to identify because a history of exposure may not be apparent, and symptoms may be nonspecific and similar to the flu.

Particulates

Particulates which can be released into the indoor environment include inorganic fibers, metals, and a variety of organic materials. Particulates in the inhalable range (10 microns aerodynamic diameter or less) are potentially hazardous to health.

Lead exposure can affect both adults and children, but children (and fetuses) are at greater risk because of their smaller body size, breathing patterns, and the way lead is metabolized in their bodies. Health effects include damage to the kidneys, nervous system, red blood cells, and potential increases in high blood pressure. Lead exposure may also result in decreased coordination and mental abilities. The effects of lead exposure can be reversed if treatment begins in a timely fashion and continues for the prescribed course of therapy; however, if treatment is delayed or stopped prematurely, then permanent brain damage can result.

Exposure to lead can occur via air, water, and food. Food is the largest contributor to the daily intake of lead for most people, but water and air can be important routes of exposure.

Asbestos is a naturally occurring mineral that can separate into long flexible fibers which are microscopic in size. Exposure to asbestos fibers does not result in immediate symptoms, but cancer and other effects can develop years after the exposure occurs. Mesothelioma, which is a cancer of the lining of the lung or abdomen, is considered to be a marker disease (specific to a contaminant) for asbestos exposure. Exposure to asbestos fibers can also result in other lung cancers and asbestosis. High levels of exposure are required to produce asbestosis, but much lower exposures can result in asbestos-related cancers. Smoking signficantly increases the risk of developing cancer. EPA has classified asbestos as a "Known Human Carcinogen."

Combustion Contaminants

Potential contaminants from combustion sources include carbon monoxide, carbon dioxide, oxides of nitrogen, sulfur dioxide, formaldehyde and other aldehydes, particulates, and water vapor.

Carbon monoxide at low concentrations can result in fatigue and drowsiness in healthy people, and it can cause shortness of breath and chest pain in people with heart disease. At higher concentrations, symptoms in healthy people can include irritability, headaches, increased respiration, impaired vision, lack of coordination, nausea, dizziness, confusion, and impaired judgment. Symptoms can be reversed if prompt medical treatment is received. At very high concentrations, coma and death result.

Carbon dioxide, which is also released from normal metabolic processes, can act as both a respiratory depressant and stimulant. Exposure to carbon dioxide has been shown to change the blood pH and carbon dioxide levels. It can also increase the respiration rate and decrease the ability to perform strenuous exercise. The long-term significance of chronic exposure to carbon dioxide is not known, but increases in respiratory and gastrointestinal disorders have been postulated. Exposure to low levels would not be likely to result in symptoms; at higher concentrations rapid pulse and breathing rates may be accompanied by a sensation of heaviness in the chest, particularly if the person is performing moderate activity.

Nitric oxide can interfere with the transport of oxygen to the tissues and may increase cardiovascular stress. Symptoms of exposure to nitric oxide at higher concentrations would be similar to those for carbon monoxide.

Nitrogen dioxide is a deep lung irritant which can also result in irritation of the eyes, nose, and throat. Some epidemiological studies suggest that children who are exposed to gas stove emissions experience increased rates of respiratory illness, but the evidence is mixed, and not conclusive. Changes in lung function have also been observed in laboratory studies of adults exposed to nitrogen dioxide, but this evidence is also mixed. Asthmatics may be particularly sensitive to nitrogen dioxide.

Sulfur dioxide, acting alone or in combination with particulates, can result in decreases in pulmonary function at low levels, but the significance of these decreases is not known. Irritation of the eyes, nose, and throat can also result. Because of the variability in response to sulfur dioxide in normal subjects and asthmatic subjects, there may not be a no-observed-adverse-effect level of exposure.

Respirable particulates from combustion sources have been associated with eye, nose, and throat irritation; respiratory infections; and bronchitis. Symptoms of irritation may result at low exposure levels. Some respirable **polycyclic aromatic hydrocarbons (PAHs)** such as benzo(a)prene, benz(a)anthracene, and others have been associated with an increased risk of lung cancer and they are classified as "Probable Human Carcinogens" by EPA.

Radioactive Contaminants

Radon is a naturally occurring radioactive gas which does not result in immediate symptoms. It is estimated that about 15% of the lung cancer cases in the United States are due to indoor radon exposures (Pushen and Nelson,1989). Smokers are at a much higher risk than nonsmokers of developing either asbestos-induced or radon-induced lung cancer. Radon is classified as a "Known Human Carcinogen" by EPA.

Airborne Biological Contaminants

Exposure to airborne pathogens and allergens such as viruses, bacteria, fungi, dust mites, human or animal dander, excreta from insects or arachnids, or pollen can result in conditions such as Legionnaires' disease, Pontiac fever, allergic rhinitis, bronchial asthma, and hypersensitivity pneumonitis. Symptoms produced by these conditions include eye, nose, and throat irritation; shortness of breath; dizziness; lethargy; fever; digestive problems; and severe allergic reactions.

Mycotoxins, which are produced by some fungi, are toxins which can result in direct or indirect effects on the body. Exposure to some mycotoxins can result in immunosuppression or direct effects such as gastrointestinal lesions, central nervous system impairment, and suppression of the blood-forming and reproductive systems. Nonspecific symptoms such as those associated with sick building syndrome can also occur. Although the effects of these toxins are primarily associated with ingestion, it is possible for inhalation to result in toxicity (U.S. EPA, 1989).

Environmental Tobacco Smoke

Environmental tobacco smoke can contain over 3800 compounds, many of which are carcinogens and mutagens (NRC, 1986). Exposure to tobacco smoke has been associated with an increased incidence of lung cancer in healthy nonsmoking adults, and it may contribute to heart disease. Other health effects from exposure to environmental tobacco smoke include eye, nose, and throat irritation; headaches; bronchitis; and pneumonia. Children who are exposed to environmental tobacco smoke have an increased risk of pulmonary and respiratory infections. There is also some evidence that parental smoking may affect the rate of lung growth in children and increase the risk of chronic ear infections (NRC, 1986).

SYMPTOMS, CONTAMINANTS, AND SOURCES
(RM 4)

As previously discussed, the health effects of indoor air contaminants can range from irritation effects to death, and there is overlap among the types of symptoms that could be caused by individual contaminants or physical stressors. Contaminants can be classified by their effects as irritants, contaminants, narcotics and anesthetics, systemic toxicants, carcinogens, developmental and reproductive toxicants, and airborne pathogens and allergens. Physical stressors include temperature, humidity, air movement, light, and noise.

The complexity of symptom patterns can complicate the task of relating symptoms to contaminants, but a knowledge of the sources of contaminants and general symptoms for different classes of contaminants can facilitate the investigation of indoor air quality problems. Table 4-1 helps identify which specific symptoms could be caused by various contaminant classes and physical stressors. This information can help the investigator narrow the contaminant classes that are most likely causing the problem. Table 4-2 identifies specific contaminants that are associated with each contaminant class identified above, and Table 4-3 provides information on common sources of those contaminants. This information should help the investigator identify potential sources in the building that may be causing particular problems. More complete lists of sources, contaminants, and health effects are provided in Sections 2, 3, and 4 of the *Reference Manual*.

Table 4-2. Health effects of selected contaminants.[1]

CONTAMINANT	CONTAMINANT CLASSIFICATION[2]						
	I	A	A/N	ST	P/A	C	Comments
VOCs	x	x	x	x		x	many of these contaminants are neuro/ behavioral toxicants, hepatotoxicants, and cardiac sensitizers
formaldehyde	x					x	may induce allergic responses
pesticides	x			x		x	many of these contaminants are neurotoxicants, hepatotoxicants, reproductive toxicants, and sensitizers
lead				x			neurotoxic and behavioral effects which may not be reversible
carbon monoxide		x					increased frequency and severity of angina in patients; decreased work capacity in healthy adult males; headaches, decreased alertness, flulike symptoms in healthy adults; exacerbation of cardiopulmonary dysfunction in compromised patient
carbon dioxide		x					can also act as respiratory stimulant; increased respiration and decreased ability to perform strenuous tasks in humans; changes in blood pH and pCO_2; calcification of kidneys and structural changes in lungs of guinea pigs
nitrogen dioxide	x						decreased pulmonary function in asthmatics; effects on pulmonary function in children, perhaps adults; synergistic effects with other contaminants in animals and children; increased susceptibility to infection in animals; animal studies indicate decreased immune capability, changes in anatomy and function of the lungs
sulfur dioxide	x						decreased lung function in asthmatics and normal exercising males; animal studies show decreased lung function

Table 4-2. Health effects of selected contaminants[1] *(continued).*

CONTAMINANT	CONTAMINANT CLASSIFICATION[2]						
	I	A	A/N	ST	P/A	C	Comments
biological contaminants *(bacteria, viruses, molds, fungi, pollen, animal and human dander, insects and arachnid excreta)*	x				x		infectious diseases; allergic reactions; toxic effects
environmental tobacco smoke	x					x	irritation of mucous membranes, cardiovascular stress, chronic and acute pulmonary effects in children
polycyclic aromatic hydrocarbons	x					x	some are irritants and can result in cardiovascular effects
asbestos	x					x	asbestosis at occupational exposures, mesothelioma
radon						x	

SOURCE: Adapted from U.S. EPA (1989).

[1]These are effects which have been associated or are thought to be associated with the individual contaminants based on toxicology or epidemiology studies. The concentration required for manifestation of the effect depends on a variety of factors. For some contaminants, there is scientific disagreement about various effect levels, and for other contaminants, there is insufficient data to determine effect levels.

[2]**Classification Codes**
I - irritant **A** - asphyxiant **A/N** - anesthetic/narcotic **ST** - systemic toxicant **P/A** - pathogen/allergen **C** - carcinogen

Table 4-3. Potential sources of selected indoor air contaminants.

CONTAMINANT	SOURCES	
VOCs	Perfumes, hairsprays Furniture polish Cleaning solvents Hobby and craft supplies Pesticides Carpet dyes and fibers Glues, adhesives, sealants	Paints, stains, varnishes, strippers Wood preservatives Dry cleaned clothes, moth repellents Air fresheners Stored fuels and automotive products Contaminated water Plastics
Formaldehyde	Particleboard, interior grade plywood Cabinetry, furniture	Urea formaldehyde foam insulation Carpet, fabrics
Pesticides	Insecticides (including termiticides) Rodenticides	Fungicides, disinfectants Herbicides (from outdoor use)
Lead	Lead-based paint	Exterior dust and soil
Carbon monoxide Carbon dioxide Nitrogen dioxide	Improperly operating gas or oil furnace/hot water heater, fireplace, wood stove	Unvented gas heater/kerosene heater Tobacco products, gas cookstove Vehicle Exhaust
Sulfur dioxide	Combustion of sulfur-containing fuels (primarily, kerosene heaters)	
RSP *(Respirable particulates)*	Fireplace, woodstove Unvented gas heater	Tobacco products Unvented kerosene heater
PAHs *(Polycyclic aromatic hydrocarbons)*	Fireplace, woodstove Unvented kerosene heater	Tobacco products
ETS *(Environmental tobacco smoke)*	Tobacco products	
Biological contaminants	Plants, animals, birds, humans Pillows, bedding, house dust Wet or damp materials	Standing water Humidifiers, evaporative coolers Hot water tank
Asbestos	Pipe and furnace insulation Ceiling and floor tiles	Decorative sprays Shingles and siding
Radon	Soil and rock Some building materials	Water

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PROGRESS CHECK

1. **Identify the major classes of toxic substances and give an example of an indoor contaminant and its source for each class.**

2. **Identify four physical stressors which may affect health.**

3. **A homeowner calls complaining of eye, nose, and throat irritation, fatigue, and wheezing. Which classes of contaminants would you suspect?**

4. **Upon further investigation, you discover that the home is older and has not been remodeled recently. There was a broken water pipe, however, about 4 months ago which damaged a ceiling and carpeting. That is about the time when symptoms began. On which class(es) of contaminant(s) would you now focus your investigation?**

5. **What range of indoor temperature and humidity is comfortable for most people?**

LESSON 5
CONTROLLING INDOOR AIR QUALITY

There are three basic strategies for controlling the indoor air environment. First, engineering strategies (source control, ventilation, air cleaning) can be used to reduce levels of contaminants. Second, good building design and proper operation and maintenance of equipment ensure the success of engineering controls. Third, administrative controls, including both regulatory and nonregulatory government policies, encourage or require the use of controls by various parties such as manufacturers, building professionals, and other individuals.

This lesson provides a summary of engineering control strategies; discusses the importance of building design, operation procedures, and maintenance procedures; and summarizes the potential use of administrative controls through public and private sector programs.

LESSON OBJECTIVES

At the end of this lesson, you will be able to:

- **identify source control options for products and equipment that can be used to reduce contaminant concentrations;**
- **discuss the dilution and exhaust of contaminants by ventilation;**
- **discuss the removal of contaminants by air cleaning devices;**
- **identify and discuss design, operation, and maintenance strategies that can be used to control indoor air quality; and**
- **identify and discuss administrative control strategies and the roles of public and private sectors in controlling indoor air quality.**

ENGINEERING STRATEGIES *(RM 5.1, 5.2)*

Three basic engineering strategies can be used to control indoor air quality. First, source control methods reduce or eliminate contaminant emissions from the source into the indoor environment. Once contaminants are in the air, ventilation can reduce concentrations by diluting indoor air with outdoor air or by exhausting contaminants out of the building. Finally, contaminants can be removed from the indoor air by air cleaning devices.

Each of these strategies is discussed below. Table 5-1 summarizes the application of these methods to some specfic contaminants.

Source Control

Sources can be controlled by removal, substitution, changes in their design or operation, encapsulation, spatial confinement, or temporal use.

Removal of a source of indoor contamination is appropriate in situations where the source is known (for example, microbial contamination, cigarette smoking, asbestos) and is not required. In many cases less polluting alternatives can be **substituted** for sources. It should be noted that the removal of some contaminants such as asbestos and lead in lead-based painted surfaces can result in airborne emissions if removal is not conducted properly. In fact, in many situations in-place management of asbestos is more appropriate than removal.

Emissions from some sources can be reduced by changing the **design** of a source. This is usually done by a manufacturer. Pilotless combustion appliances are a good example. However, the way in which individuals **operate** or use sources also affects emissions. For example, the flame adjustment on combustion sources or the application method for pesticides or cleaners can greatly influence emissions.

A source can also be **encapsulated,** as with the use of sealants on building materials, so that the release of a contaminant into the indoor air is restricted. The use of some encapsulants, however, can release contaminants such as VOCs into the indoor air for varying periods of time.

Building occupants can control the release of contaminants through the placement and use of sources. One technique, **spatial confinement,** is to place a source in a confined area that has limited air exchange with the remainder of the living space. An example of spatial confinement is to place a hot water heater in a garage.

The **temporal use** of sources can also reduce exposure, even though emissions are not changed. Using solvents or pesticides when no one else is present, for example, will minimize exposure.

Source control can significantly improve indoor air quality, and in some cases, it is the only solution. Most source control methods require little or no upkeep and result in minimal energy penalties. Disadvantages in some cases, however, include high initial costs for using more expensive materials, appliances, construction practices, or manufacturing processes.

Ventilation

Ventilation is needed in structures for three basic reasons: 1) to replace air used by combustion sources; 2) to remove excess humidity; and 3) to remove contaminants released by indoor sources.

Because ventilation systems are so closely tied to heating and cooling systems, all of these systems must be considered when evaluating indoor air quality. The ventilation system is especially critical in energy efficient construction. Section 5 of the *Reference Manual* provides a review of different heating and air supply systems that might be encountered in residential investigations.

Table 5-1. Examples of indoor air contaminant control strategies.

CONTROL METHOD	CONTAMINANT
Source Control	
Removal	
stop smoking	environmental tobacco smoke
eliminate kerosene heaters from living space	kerosene heater emissions
separate garage from house	auto emissions
remove pets from living space	allergens
construct physical barriers for termite control	organics
Substitution	
use wood or metal building materials and furnishings instead of interior grade particleboard and plywood	formaldehyde, other organics
use fiberglass or other type of insulation instead of urea-formaldehyde foam	formaldehyde
replace combustion appliances with electric appliances	combustion contaminants: oxides of nitrogen, carbon monoxide, sulfur dioxide, particles, carbon dioxide
replace a portable vacuum system with a central system	particulates
replace materials that collect dust, have water damage, or provide food sources for insects with other materials	allergens
substitute materials which cause allergies with those that don't	a variety of chemical and biological allergenic agents
replace pesticides with physical or biological controls	organics
Changes in Design or Operation	
pilotless combustion appliances and more efficient burner design for gas stoves, gas and kerosene heaters	combustion contaminants
adjust and maintain combustion appliances to provide an efficient burn	combustion contaminants
HVAC system components that increase outdoor air ventilation rates	allergens
heat exchangers with condensate drains	allergens

(continued on next page)

Table 5-1. Examples of indoor air contaminant control strategies *(continued)*.

CONTROL METHOD	CONTAMINANT
Source Control (continued)	
Prevention	
do not build in areas of high radon potential such as areas where uranium or phosphate tailings have been used as fill materials	radon
Encapsulation	
cover materials that contain urea formaldehyde with shellac, varnish, or other barriers[a]	formaldehyde, organics
seal asbestos-containing building materials	asbestos
seal cracks in basements walls and concrete slabs with polymeric caulks[a]	radon
cover basement walls and concrete slabs with epoxy paint, polymeric sealant, or vinyl sheeting[a]	radon
Spatial Confinement	
place combustion appliances in isolated, ventilated rooms	combustion contaminants
limit smoking to specific areas	environmental tobacco smoke
use solvents and other hazardous chemicals outdoors or in confined, ventilated areas	organics
Temporal Use	
use solvents only when natural ventilation is adequate or when the number of people exposed is minimized	organics
use pesticides only when children, pets, and other adults are not exposed	organics
Ventilation	
Natural and Mechanical Ventilation	
use according to appropriate standards	all contaminants

[a] Note that the use of sealants can result in the release of contaminants such as VOCs for varying periods of time.

Table 5-1. Examples of indoor air contaminant control strategies *(continued).*

CONTROL METHOD	CONTAMINANT
Ventilation (continued)	
Local (Exhaust) Ventilation	
use in kitchens, bathrooms	cooking contaminants, moisture, microorganisms
ventilate crawl spaces	radon and decay products; termiticides
ventilate areas where solvents and other organics are used	organics
apply ventilation techniques such as sub-slab ventilation	radon and other soil gases
Air Cleaning	
Filtration, Electrostatic Precipitation	
use HEPA filtration and electrostatic precipitation	dust, allergens, inhalable particles
use flat or pleated filters for HVAC equipment	dust, some allergens

If outdoor air is of acceptable quality, ventilation can effectively reduce contaminant concentrations by diluting contaminated air with cleaner outdoor air and exhausting contaminants to the outdoors. If the outdoor air is contaminanted, it may have to be treated to prevent the transfer of contaminants indoors. The exchange of outdoor air with stale contaminated air occurs through the mechanisms of infiltration and exfiltration, natural ventilation, or mechanical ventilation.

Infiltration

Minimizing infiltration is an energy conserving strategy that can reduce heat loss, maximize thermal comfort, and allow for greater control of ventilation rates. These advantages, however, can be offset by the potential of increasing the damage caused by condensation on cold surfaces. Both of these factors must be considered during construction, renovation, and problem-solving.

Infiltration can be controlled by either reducing the surface pressures driving the flow of air around a structure or reducing the air leakage into a structure. Landscaping can be used to reduce surface pressures on the building. Air leakage can be reduced by first identifying the leakage points and then sealing them. Leakage sites can be identified using the fan pressurization method (independent of weather), smoke sources, or by noting the leakage points when the building is depressurized in cold weather (ASHRAE, 1989). Caulking, weatherstripping, and storm windows or doors can be used to seal leakage points.

One of the most effective ways of reducing air leakage through the building envelope is construction of a continuous air or air/vapor retarder. The air/vapor retarder stops or slows the movement of air and water vapor; an air retarder only controls air movement, not water vapor. The air or air/vapor retarder must be carefully installed and sealed at all window and door openings; ceiling, wall, and floor junctions; electrical, plumbing, or other service outlets. Details of construction techniques can be found in Mann (1989), Lenchek *et al.* (1987), or other housing construction books.

Examples of air/vapor retarders include polyethylene sheeting, aluminum foil-faced foam insulation boards, gypsum board primed with vapor-retarder paint as a sealant, and paper-faced insulation batts. Tyvek housewrap (spunbonded polyolefin) is an air retarder (not a vapor retarder) that can reduce infiltration by 30-40% (Mann, 1989). Vapor retarders must be installed on the warm side of insulation to prevent condensation from occurring on the insulation. Air retarders can be installed on the warm or cold side of the framing wall, depending on the material.

Houses with low infiltration should have mechanical ventilation systems or air intake openings to ensure good indoor air quality and proper humidity levels; combustion appliances should be equipped with a separate outdoor combustion air supply to prevent backdrafting of flue gases.

Natural Ventilation

Natural ventilation can be provided through windows, skylights, roof ventilators, doors, louvers, jalousies, specially designed inlet or outlet openings, stacks connected to registers, or other openings. Air intakes should be located so that fresh air is drawn into the building, but contaminated air from nearby sources is not. Exhausts should be located so that they do not exhaust into air intakes of the same or other buildings.

Opening windows, doors, and skylights can produce effective ventilation, but this method is limited by weather conditions. Special openings such as wall vents can also be installed to provide fresh air ventilation. All windows should be accessible and operable.

For maximum effectiveness, windows should be located in opposing pressure zones. Two openings on opposite sides of a space increase the ventilation flow. Ventilation to a greater area can be provided by locating openings on adjacent sides. If a room has only one external wall, widely spaced windows can maximize airflow. Windows at the same level and near the ceiling will be less effective. To take advantage of the stack effect, the vertical distance between openings should be maximized. Thermally induced ventilation is least effective for openings close to the NPL. The greatest air flow per unit area of total opening will result from inlet and outlet openings that are nearly equal in size.

Roof ventilators are weather-proof air outlets that use the wind to help draw air out of the interior space. It is important to position the roof ventilator so it receives the full, unrestricted wind. Roof ventilators, which can be powered or unpowered, come in a variety of configurations that can be installed on the roof or in gables. These devices prevent moisture from trapping in the attic and reduce cooling costs in the summer. Stack or vertical flues should also be located so that wind can act on them from any direction.

Mechanical Ventilation

Mechanical ventilation results in air exchange by using fans to force the air to move between the inside and outside of a building. Mechanical ventilation can remove contaminants from entire buildings or from localized areas within a building. In each case, fans, which can range in size from small fans to large whole house fans, are used to force air out of or into a house, to recirculate air, to cool or heat air, or to clean air by passing it through a filter.

Exhaust ventilation uses exhaust fans to draw air out of a building, creating a slight negative indoor pressure which draws fresh air in through available cracks and openings. Exhaust fans that are properly rated and ducted to the outside can effectively remove contaminants and moisture from entire houses or from localized areas such as kitchens, bathrooms, and clothes dryers.

The best method of removing contaminants from the kitchen (combustion gases, smoke, grease, moisture, and odors) is a range hood exhaust which is ducted to the outside. An aluminum mesh screen filter, which can easily be removed and cleaned, traps grease; and a fan or blower exhausts smoke and moisture to the outside. Ductless hoods filter the air through aluminum and activated carbon filters and return the air back into the kitchen through louvers in the front of the hood. These hoods have been used more often in recent years as an economical alternative to ducting to the outside. The filters *must* be cleaned regularly. Ductless hoods are far less effective than ducted hoods in removing contaminants and are *not* recommended.

Fans which exhaust the entire kitchen can also be used, but they are not as effective as ducted range hoods. If kitchen exhaust fans are used they must be ducted to the outside and should be located as close to the range as possible.

Whole house ventilation can be very effective in cooling an entire house without air-conditioning. Whole house exhaust fans (sometimes called attic fans) can be installed in a variety of locations including in the attic, on the roof, in a wall, or in a window. Regardless of location, it is important for air to circulate freely to the fan. Openings may be sealed during the winter to reduce heat loss. If the exhaust fan is not balanced by infiltration, air intake vents, or windows, a backdraft from chimneys or flues can result, or soil gases such as radon may be drawn in through the basement foundation. If radon is a problem, a whole house fan may not be advisable.

Supply ventilation uses supply fans to draw air indoors, causing a slight positive indoor air pressure which tends to force air outside through available cracks or openings. Supply fans can be used to ventilate entire homes or only one level of a home. Advantages of using supply fans include reductions in contaminant levels, reductions in cold drafts from cracks, and the ability to control the source of supply air.

Central forced-air systems are heating, ventilating and conditioning systems that rely on fans to circulate room air through ducts, pass the air through a filtering system to clean it, and redistribute the air throughout the home after the air has been heated, cooled, or otherwise conditioned. Residential central forced-air heating and cooling systems can be modified to reduce contaminant levels by installing air cleaning devices and/or an outdoor air connection (Figure 5-1).

The outdoor air connection is a three-to six-inch duct that brings outside air into the return side of the furnace (where the room air enters the furnace). The amount of outdoor air that is introduced is controlled by a damper. Care should be taken to ensure that the outdoor intake vent is located away from outdoor sources of contamination.

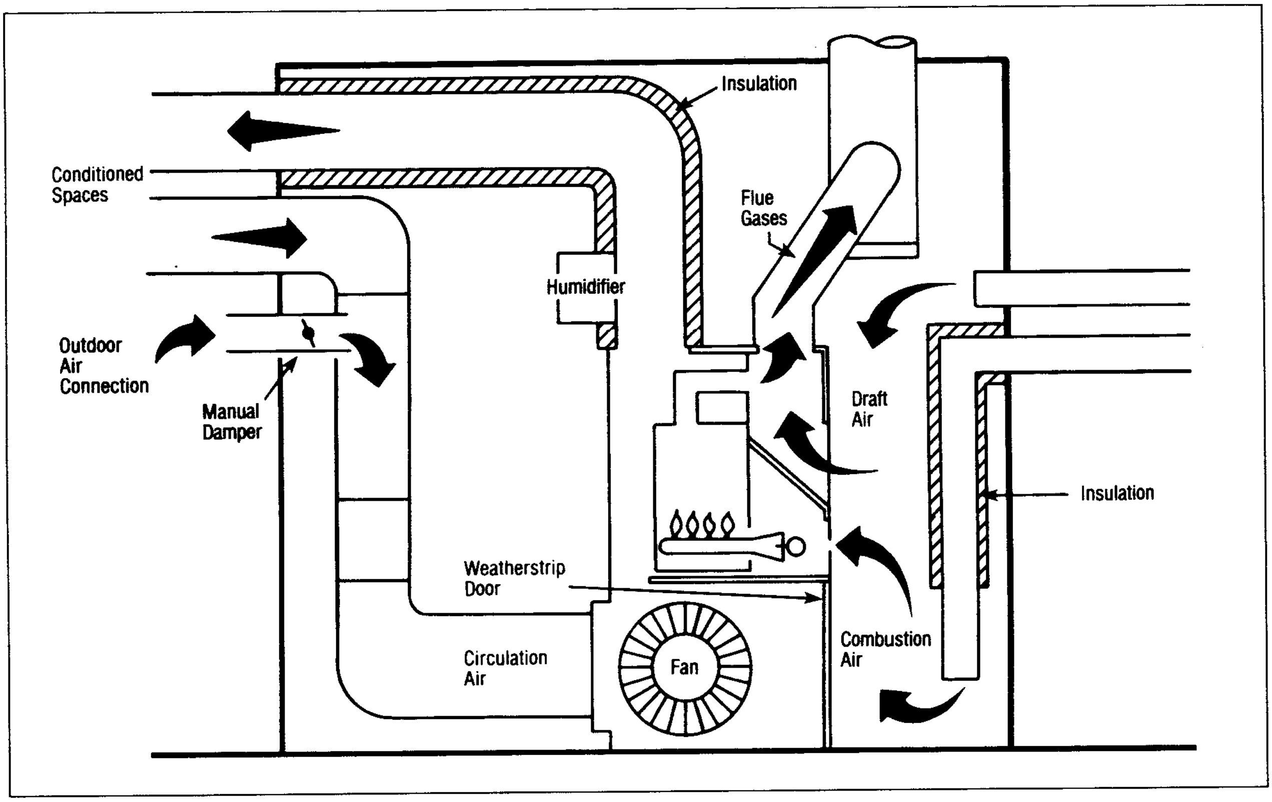
Some jurisdictions now require an outdoor air connection in new houses. The cost of an outdoor air connection in most new construction is minimal (about $100), but there is an energy penalty regardless of whether the house is new or older.

The outdoor air connection is different from the combustion air supply for the furnace. Many existing furnaces can be retrofitted with an outdoor air supply, but care should be taken to make sure that the furnace can accommodate this kind of connection. If an outdoor air supply can be installed, it can provide a reasonably cost effective method for providing sufficient dilution ventilation. During cold weather, condensation can occur.

Evaporative coolers (also known as swamp coolers) can result in effective air exchange (10 to 20 ach), and they can simultaneously cool and humidify the air. They are most effective in dry climates. As outside air is forced through a water saturated filter to the inside of a structure, the air is cooled as water absorbs heat from the air and evaporates. One disadvantage of evaporative coolers is that the filters can foster microbial growth, and they should be cleaned and serviced regularly.

Ventilation with heat recovery can be an effective method for providing outdoor air ventilation while

Figure 5-1. Example of a residential heating system with an outdoor air connection.



SOURCE: Adapted from *Energy Design Update.* Cutter Information Corp: 37 Broadway, Arlington, MA 02174. Used with permission.

maximizing energy efficiency. Heat recovery ventilators (air-to-air, ground-to-air, or water-to-air heat exchangers) provide controlled ventilation at high air exchange rates while conserving the energy needed for heating and cooling. A heat recovery ventilator usually consists of two small fans and a heat transfer unit which are mounted in a box that is connected to the interior and exterior of the house by metal ducts. There are many different types of heat transfer units which consist of a matrix of alternate layers of metal, plastic, or treated paper plates. (Paper plates may pose problems because they tend to collect moisture and dirt and can become perforated).

During the heating season the supply fan draws cold outside air through specific passages in the matrix before it is distributed throughout the house. At the same time, the exhaust fan draws warm room air from the house through alternate passages in the matrix. The heat from the exhaust air is absorbed by the matrix and transferred to the supply air. The two airstreams never meet.

As the warm air comes into contact with the cool plates of the matrix, condensation can form. The condensed moisture is a problem for two reasons. It can freeze and block the movement of air, and it can become a reservoir for bacteria and fungi which can be carried into the room air. Improved units have an automatic defroster and drain to prevent moisture accumulation.

Heat recovery ventilators can effectively ventilate tightly sealed areas and they are energy efficient. The units typically are mounted in the basement, crawl space, utility room, or attic; they can also be mounted in walls or ceilings. Another advantage is that they balance supply and exhaust air streams. Disadvantages include cost ($150 to $1500) and potential problems associated with condensation in older units. These units require regular cleaning to reduce the risk of microbial contamination. Calculations of overall energy efficiency should include the energy required for the fans. Units tend to be more cost effective in colder climates.

Air Cleaning Devices

Air cleaning devices can also be used to reduce the levels of some contaminants, but they are not a substitute for source control or adequate ventilation. Contaminants can be removed either from the outdoor air before it enters the home or from the recirculating air inside the home. Air cleaners for residential use can be effective in removing some particles, but may be of limited value in removing gases and vapors. If air cleaning devices are used, they must be properly sized and maintained.

Commercially available air cleaning devices are based on the principles of filtration, electrostatic attraction, or adsorption. Filtration and electrostatic attraction reduce particulate contaminants and adsorption reduces gaseous contaminants. Air cleaners come in many different sizes and configurations, and their performance varies considerably.

Portable units include small table top units and larger console units which are intended for localized situations. Some air cleaners can be located centrally, or in the HVAC ducts, to clean air from the entire house.

It should be noted that expected removal efficiencies for air cleaning devices are not the same as the effectiveness of the unit in actual use. Efficiency only measures the percent removal of contaminants in the air that flows through the air cleaning device. Effectiveness in use depends on how much of the interior air actually goes through the unit in a given time period. These differences are discussed in more detail later in this lesson. A summary of available information on air cleaning devices is available from EPA (U.S. EPA, 1990).

Removal of Particles by Filtration

Filtration removes particles by a mechanical barrier which allows only particles of a certain size to pass through. Filters can be made of fiberglass, metal, or natural fibers. Some filters are disposable, and others must be cleaned for reuse. As the air stream passes through the filter, particles are removed by the fibers through direct interception, inertial deposition, diffusion, and electrostatic effects. The relative importance of each of these collection mechanisms varies with particle size. Diffusion dominates for particles less than 0.01 microns in diameter while interception and inertial impaction dominate the removal of particles greater than 1.0 micron in diameter. For all filters, there is a particle size for which the removal efficiency is at a minimum. Some of the factors that affect filter efficiency include fiber size, fiber density, air flow rate, and particle diameter.

Mechanical filters can be grouped into panel filters and extended surface filters, (including high efficiency particulate air (HEPA) filters). Section 5 of the *Reference Manual* compares the performance of these types of filters based on standard ASHRAE performance tests (tests are explained in the *Reference Manual*).

Panel filters consist of a filtering medium (coarse glass, animal hair, synthetic fibers, animal fibers, metals, foils) held in place by a rigid or flexible frame. The filter fibers have a low packing density and are usually coated with a viscous substance (oil, for example) which traps particles. Panel filters are inexpensive (approximately $1-$2 for furnace filters). They are characterized by a low pressure drop across the filter and a high removal efficiency for very large particles such as lint, but a very low removal efficiency for respirable particles. Permanent panel filters must be cleaned regularly, usually with steam or water and detergent.

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The filters typically used in residential forced-air heating and cooling systems are low air resistance fiberglass panel filters that remove larger particles. They are used primarily to keep the ventilation system clean and, in part, to protect the equipment. Some individuals may be sensitive to the oils, resins, disinfectants, and scents that may be used in the manufacture of the filters. These low efficiency filters are also used as prefilters in air cleaners.

Extended surface filters (also called pleated filters) are basically panel filters that have been pleated or folded to provide more filter surface per unit area of filter face. The filter media may stand alone or be encased in a frame. These filters are more efficient and can hold more dust than comparable panel filters. By extending the surface of the collecting medium, the flow velocity through the filter is reduced, and this reduces the pressure drop across the filter. Therefore, denser and more efficient filter media can be used while maintaining acceptable pressure drops.

High efficiency particulate air (HEPA) filters are extended filters that remove submicron particles with high efficiency (greater than 99.97% removal efficiency for particles 0.3 microns and larger). In some designs, HEPA filters consist of a core filter that is folded back and forth over corrugated separators that add strength to the core and form the air passages between the pleats. The filter is composed of very fine submicron glass fibers in a matrix of larger fibers (1 to 4 microns).

In the typical furnace system, the standard low efficiency filter can be replaced by a medium efficiency filter but not by a HEPA filter. If it is not part of the original installation, the HEPA filter must be installed in a separate housing. Some manufacturers, however, do make HEPA filter-containing furnaces.

HEPA filter room and whole house air cleaners range in cost from about $200 to $2000. Air flow capacity ranges from about 100 cfm for smaller units to 2000 cfm for larger units.

Charged-media filters combine aspects of both mechanical filters and electrostatic filters, and they can be both ionizing and nonionizing. The electret filter is a relatively new product that consists of a charged-media filter that attracts dust particles onto permanently charged plastic films or fibers called electrets. The positive and negative charges can be produced by the friction of air flowing over the filters or as a result of high-voltage imprinting during manufacture. These filters have high particulate removal efficiencies, and they do not produce ozone. However, they must be cleaned regularly, and there is some controversy about their efficiency after they have been loaded with particles (Fisk *et al.*, 1987).

Removal of Particles by Electronic Air Cleaners

Electronic air cleaners use an electrical field to trap charged particles. Like mechanical filters, they can be installed in central heating and/or cooling system ducts, or they may be portable units with fans. Electronic air cleaners include electrostatic precipitators; ion generators are sometimes classified as electronic air cleaners.

Electrostatic precipitators apply a charge to particles which are then removed from the air by becoming attracted to oppositely charged plates. Electrostatic precipitators have a high removal efficiency for small particles.

In residential and commercial applications, **ionizing flat-plate precipitators** are widely used. Residential units typically consist of two stages. Particles are ionized in the first stage and collected in the second stage. In some cases, the electrostatic precipitators have prefilters to remove large particles or adsorbents such as charcoal to remove gaseous contaminants after air leaves the precipitator. The removal of gaseous contaminants is discussed below.

Because of the high voltages which are used in electrostatic precipitators, some safety precautions are needed. Electrostatic precipitators should shutoff automatically when doors to the high voltage parts are opened.

The collection surfaces of electronic electrostatic precipitators must be cleaned regularly (manufacturer's recommendations may be once per month to once every few months with soap and water in residential units) to remove the accumulated dust particles. In some air cleaners the cells must be removed for cleaning, but in other designs the cells are cleaned in place.

The generation of ozone may be a problem if there is continuous arcing and brush discharge or if the units are not properly ventilated or maintained. Some individuals may be sensitive to ozone concentrations of 0.1 ppm or less (WHO, 1987).

Average removal efficiencies of up to 98% at low air flow velocities (150 to 350 fpm) can be achieved with individual units (ASHRAE, 1989). Efficiency decreases as the collecting plates become loaded or if the collection velocity is variable or too high. Whole house units have expected removal efficiencies of 50% to over 95% depending on the unit and the particulate to be removed (ASHRAE, 1989).

Ion generators are portable devices that use static charges to remove particles from the air. These devices charge particles so they are attracted to surfaces such as walls, floors, draperies, occupants, and furniture. These units may have a collector to attract the charged particles back into the unit or may be equipped with other removal devices such as mechanical filters. If ion generators do not have collection units, soiling of walls and other surfaces may occur. Advertising claims may include statements about the harmful effects of positive ions on health and the beneficial health effects of negative ions, but these claims are controversial.

Removal of Gases

The technology for removing gases from residential and commercial buildings is not as established as particulate control technology, and it is not possible with current data to evaluate the overall effectiveness of air cleaning devices in removing gaseous contaminants.

Adsorption is a technique that is used to remove gaseous contaminants from indoor air environments. Gaseous contaminants are attracted to and retained on the surface of materials such as activated charcoal, alumina, and silica gel. The gas is the adsorbate and the solid material is the adsorbent. The degree of adsorption depends on the surface area of the adsorbent, the volume and size of pores in the adsorbent, the concentration of the contaminant, and the chemical properties of the contaminant. The efficiency of adsorption devices is inversely proportional to the amount of contaminant which has been captured. As the adsorbent is used over a period of time, efficiency decreases.

Physical adsorption is a process in which the contaminant is retained on the surface of the adsorbent by the forces of attraction between the contaminant and the adsorbent. Eventually the adsorbent becomes saturated and unable to remove any more of the contaminant. Chemisorption is a process in which molecules of the contaminant become chemically bonded to the surface of the adsorbent. It is a more selective process than physical adsorption, and it is often irreversible.

Adsorbents need a large surface area per unit mass in order to efficently remove contaminants. For air cleaning applications, air can be passed through a bed of adsorbent that is up to a few centimeters thick.

Activated charcoal is the most commonly used adsorption medium. When activated charcoal becomes saturated, it must be replaced or regenerated. Because it is nonpolar, it can remove some organic compounds, particularly high molecular weight compounds, such as those contained in cooking odors or in solvents which are used in paints, polishes, waxes.

Until recently, tests evaluating the removal of gaseous contaminants by activated carbon have been conducted using high concentrations of contaminants. Recent work by EPA suggests that the useful lifetime of activated carbon filters at the low concentrations (ppb range) typically found in indoor air may be short because contaminants quickly penetrate the 6-inch deep carbon filters which are currently marketed for odor control in in-duct systems (Ramanathan *et al.*, 1988). Another concern is the ability of activated carbon to reemit trapped contaminants (U.S. EPA, 1990).

Adsorbents can be impregnated with other chemicals (potassium permanganate, phosphoric acid, sodium sulfite, sodium carbonate, and metal oxides) to improve their performance. Activated charcoal alone, for example, is not effective for compounds with low molecular weights such as formaldehyde. Formaldehyde can be adsorbed by sorbents such as activated alumina impregnated with potassium permanganate and by activated carbon impregnated with sodium sulfide. However, effectiveness of formaldehyde removal during residential applications has not been verified, and some data suggest that large quantities of sorbent and high air flow rates may be needed for effective removal.

Effectiveness of Air Cleaners

Efficiency vs effectiveness: Efficiency is a term that refers to the ability of the collecting medium to capture contaminants from the airstream that passes through it. Efficiency is usually expressed as a percent. The effectiveness of an air cleaner refers to its ability to reduce particulate concentrations in the room air. The effectiveness of an air cleaner is determined by its efficiency, the amount of air handled, position in the room, and other factors.

It is important to distinguish between efficiency and effectiveness. A filter may be rated 99% efficient which means that it will remove 99% of the particles that move through it, but if the filter has a low flow rate (if it only handles 10 cfm) it will take a relatively long time to treat the air in a typical room of 1000 ft^3. This filter can be described as efficient, but it is not effective.

Particulates: There is controversy about the ability of air cleaners to reduce the health effects produced from larger particles such as pollen, house dust, molds, animal dander, and some other allergens. It is thought that these larger particles settle on surfaces before they can be captured by the air cleaning device.

Pollen and some molds, however, can be effectively controlled by an air conditioner. Also, it appears that some household dust allergens can be as effectively controlled by impermeable coverings on mattresses as by air cleaners (U.S. EPA, 1990).

There are several factors which can affect the performance of particle air cleaners. For example, if filters do not fit snugly into holders, effectiveness decreases because air bypasses the filter. Some portable units, in particular, may not have effective seals. Also, air cleaners should be properly sized for the space to be cleaned. Undersized units will not be effective.

The placement of portable devices is important. When sources are known, units should be placed so that the intake is near the source. The outlet of air cleaners should not be blocked by walls, furniture, or other obstructions.

The efficiency of air cleaning filters is rated by ASHRAE Standard 52-76. This standard allows the efficiency of different units to be compared with one another, but it does not rate the effectiveness during use. A more recent standard developed by the American National Standards Institute and the Association of Home Appliance Manufacturers (ANSI/AHAM AC-1-1988 standard) rates the clean air delivery rate (CADR) for portable air cleaners while in use (AHAM, 1988). The CADR is a measure of the volume of air that a device cleans of a specific test contaminant. A CADR rating of 100 for dust means that the air cleaner may reduce dust particles to the same concentration as would be achieved by adding 100 ft^3 of "clean" air each minute. The effectiveness of room air cleaners is rated for test dusts of tobacco smoke, pollen, and dust. The ANSI/AHAM program is relatively new and only a limited number of air cleaners have been tested. Section 5 of the *Reference Manual* provides more information on these standards.

Evaluations conducted by Consumers Union (CU, 1985; 1989) and others have shown that portable air cleaners vary considerably in their ability to remove particulates from indoor air. In the 1989 evaluation, units with electrostatic precipitators and HEPA filters (CADRs in the range of 120-290 cfm) more effectively removed particulates and smoke than units with flat filters (CADRs in the range of 100-130 cfm). CADRs for 21 console units were higher (30-290 cfm) than for 6 table-top units (10-130 cfm). Overall, there was considerable variability among the units.

Gases: There are limited data on the effectiveness of air cleaners in removing gases. The performance of solid sorbents depends on the flow rate of air through the sorbent; the concentration of the contaminant; the presence of other gases, vapors and humidity; the amount of sorbent; and the physical and chemical characteristics of both the contaminants and the sorbent. In general, as contaminants accumulate on the sorbent the efficiency of the sorbent decreases.

Cleaners for gaseous contaminants are usually rated in terms of the sorption capacity and penetration time, which is the amount of time before the capacity of the sorbent is reached. One problem in evaluating these cleaners is that the testing methods are not standardized, but the National Institute of Standards and Technology is in the process of developing a standard method to be used in evaluating the effectiveness of media used for gaseous contaminant removal (U.S. EPA, 1990). Evaluations are also limited because the effect of additional contaminants on the removal process has not been evaluated, and the tests do not replicate the actual indoor environment. Preliminary information indicates that air cleaning devices may be able to reduce some specific contaminants at least on a temporary basis, but they probably cannot remove all of the various contaminants which are typically present in an indoor environment (U.S. EPA, 1990).

DESIGN, OPERATION, AND MAINTENANCE STRATEGIES *(RM 5.1, 5.2)*

Adequate design, proper operation and maintenance, and appropriate energy management of commercial and residential buildings are critical for maintaining good air quality. Architects and builders can play a significant role in minimizing indoor air quality problems by ensuring the:

- consideration of proposed uses of space and potential sources of contaminants;
- design of interior spaces to provide good air flow, adequate light levels, and low noise;
- consideration of potential heat loads due to penetration of sunlight;
- use of low contaminant-emitting building materials;
- design of heating, ventilating, and cooling systems to exhaust contaminants from known sources and to ensure an adequate supply and distribution of outdoor ventilation air throughout the building;
- design of the heating, ventilating, and cooling system to prevent outside contaminants from entering the outside air intake, and to provide adequate access to filters, condensate pans, ductwork, and other system components;
- adherence to minium code requirements; and

- incorporation of additional control measures into the design, if necessary, to maintain a healthful indoor air environment.

Responsiblity for good air quality does not end with the design and construction of buildings. Building managers and individuals can promote good air quality in both new and older construction by:

- operating equipment properly;
- implementing maintenance activities such as regular cleaning of heating, ventilating, and cooling components which minimize indoor air quality problems;
- developing indoor air quality protocols for the use of cleaning products, paints and related supplies; pest management; roof repairs or replacement; and odor control;
- following energy management techniques consistent with good indoor air quality management practices.

Since the energy crisis of the 1970s, the concept of energy management in buildings has become an important objective of designers and managers of residential and commercial buildings. There has been a push to tighten building envelopes and reduce outdoor ventilation air in order to save energy costs. However, building managers and homeowners should understand that energy conservation strategies *must incorporate the need for outdoor ventilation air.* The proper operation of HVAC systems can be a very effective strategy to control indoor air contaminants at the same time that energy is conserved.

ADMINISTRATIVE CONTROLS

Administrative controls include actions which inform the public about indoor air quality issues or actions which encourage or require that certain steps be taken to protect building occupants. The administrative control of indoor air pollution problems includes both regulatory and nonregulatory options.

Nonregulatory Approaches

Government, consumer protection professionals, health professionals, and industry all play important roles in furthering nonregulatory approaches to indoor air quality problems. Research, training and technical assistance, public information, and voluntary standards and guidelines may be used to identify indoor air quality problems and solutions.

Research is used to determine the nature of the problem, its magnitude, and methods of control. The Federal government is a leader in conducting and sponsoring research, and both the public and private sectors benefit from Federal government research activities through technology transfer programs. Academic institutions, industry, state and local governments, and professional associations also contribute to the scientific data base.

Training and technical assistance programs develop expertise which can be used to implement policy objectives, solve problems, or establish indoor air quality programs.

Information dissemination to inform the public about indoor air quality problems and solutions is particularly important because a well-informed individual can significantly reduce exposures through the wise selection and use of products and services.

Standards and Guidelines

Standards and guidelines are frequently issued by private sector organizations and governments. While the majority of private sector standards are voluntary (nonregulatory), they can become the basis for acceptable professional practice, and are often incorporated into government regulations by reference. Governments can issue standards and guidelines as either regulatory or voluntary policies.

Standards and guidelines that are most important to indoor air include:

Air quality standards which specify maximum concentrations of a contaminant beyond which health risks are deemed to be unacceptable;

Source emission standards which specify maximum rates at which a contaminant can be emitted from a source;

Ventilation standards which specify minimum rates for the introduction of outdoor air into indoor spaces;

Building codes which are frequently issued as regulations by state and local governments and provide design and construction specifications for buildings and building systems;

Maintenance guidelines which specify procedures and timetables for operating and maintaining building equipment; and

Diagnostic and measurement protocols which establish methodologies for measuring and assessing indoor air quality problems.

Regulatory Approaches

Regulations impose requirements on individuals or organizations and carry the force of law. Generally, they contain provisions for either civil or criminal penalties for noncompliance. The most common regulations relevant to indoor air are specific to a given contaminant or source. Different types of regulations include:

- a ban or restriction on the use of specific chemicals or products such as asbestos or chlordane;
- a requirement that products meet certain standards such as the requirements for oxygen sensors on unvented gas heaters or the product standards for formaldehyde in manufactured housing;
- requirements for testing and certification, such as for pesticides prior to manufacture;
- labeling standards for specific products such as cleaners, pesticides, sealants, paints, and solvents which require disclosure of information about chemical contents, effects, and instructions for proper use.

ROLES AND RESPONSIBILITIES *(RM 5.3)*

Many different entities in the public and private sectors are responsible for the control of indoor air quality through the implementation of these strategies. Some of their roles and responsibilities are outlined in Table 5-2. It is clear that none of these groups or roles can stand alone; each depends on the expertise and cooperation of the others for the effective control of indoor air quality problems.

Private Sector Roles

The private sector has a significant role to play in both the policy-making process and in the design, operation, and maintenance of systems and products to ensure a healthful indoor air environment.

- Manufacturers, engineers, architects and builders can design, manufacture, and build products and structures that minimize indoor air quality problems.
- Occupants can properly use and maintain products and equipment, and building owners and managers can properly operate and maintain buildings to reduce indoor air quality problems.
- Environmental health and other related professionals can educate the public about indoor air quality, conduct research to

identify problems and recommend solutions, and participate in the policy-making process.

- Consumers are responsible for properly maintaining their homes and making intelligent choices about consumer goods and services.

Governmental Roles

Federal, state, and local governments have significant responsibilities in the effort to control indoor air contamination. For other environmental health problems, the Federal government has developed mandatory standards directed toward limiting the levels of contaminants in the environment, but in the area of indoor air quality, it has taken the lead in research and in making new information available. This shift in its role is due in part to the widespread nature of indoor air quality problems and the inherent difficulties in regulating the sources of indoor air contaminants, especially in residences.

At the federal level, there are many agencies such as the EPA, Department of Energy, Consumer Product Safety Commission, Department of Transportation, Department of Health and Human Services, and others which are involved in indoor air quality activities. All of these agencies are important resources for consumers, the private sector, and state and local agencies. Current information about federal agencies, their activities, status of programs, and contact persons can be obtained from a publication which EPA updates on an annual basis (U.S. EPA, 1990). This publication, *Current Federal Indoor Air Quality Activities*, can be obtained from the Public Information Center, U.S. EPA, Washington, D.C. 20460.

The establishment of state and local indoor air quality programs is an important strategy for ensuring programs and activities that are responsive to state and local needs. State and local governments must take the lead in identifying and studying local problems and adopting appropriate control strategies. Sometimes these activities have been conducted with the assistance of the Federal government (for example, the radon testing program). EPA in conjunction with the Public Health Foundation has published a document, *Directory of State Indoor Air Contacts* which identifies state agencies and agency contacts by indoor air quality contaminants/problems (U.S. EPA, 1988). This directory is also available from the EPA Public Information Center.

One of the primary ways that state and local governments can control indoor air pollution is through the adoption and enforcement of building codes for the design, construction, and ventilation of residential and commercial buildings.

Table 5-2. Public and private sector roles.

PUBLIC AND PRIVATE SECTOR ROLES

Individuals	Consumer and Health Professionals	Manufacturers	Building Owners and Managers	Builders and Architects	State and Local Governments	Federal Government
Find low emission products in purchasing decisions.	Be knowledgeable of symptoms, effects, and mitigation and advise clients.	Adopt test procedures and standards to minimize product and material emissions.	Adopt ventilation maintenance procedures to eliminate and prevent contamination and ensure an adequate supply of clean air to building occupants.	Adopt indoor air quality as a design objective.	Conduct studies of specific problems in state or local area and adopt mitigation strategies.	Conduct research and technology transfer programs.
Maintain and use products to minimize emissions.	Develop information and education programs to constituent publics.	Adequately label products as to emission level, proper use, and maintenance of products.	Use zone ventilation or local exhaust for indoor sources.	Ensure compliance with indoor air quality ventilation standards.	Establish building codes for design, construction, and ventilation requirements to ensure adequate indoor air quality.	Coordinate the actions of other sectors.
Exercise discretionary control over ventilation to ensure clean air supply.		Substitute materials to minimize emissions from products manufactured.	Develop specific procedures for use of cleaning solvents paints, herbicides, insecticides, and other contaminants to protect occupants.	Adopt low emission requirements in procurement specifications for building materials from manufacturers.	Enforce and monitor compliance.	Conduct specific programs to inform encourage, or require specific sectors to take actions toward mitigation.
Be knowledgeable of indoor air quality problems and take actions to avoid personal exposure.		Develop training programs for commercial users to ensure low emissions. Conduct research to advance mitigation technology.	Adopt investigatory protocols to respond to occupant complaints.	Contain or ventilate known sources.	Educate and inform building community, health community, and public about problems and solutions.	

SOURCE: EPA (1989)

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PROGRESS CHECK

1. **What are the three general strategies that can be used to control indoor air contamination?**
2. **What are the source control options that can be used to reduce contaminant concentrations? Give one example of each.**
3. **Which removal options are based on increasing the exchange of contaminated air with fresh, clean air?**
4. **Which options are based on the removal of contaminants from the air stream by physical or chemical means?**
5. **Compare ways of controlling or providing ventilation using infiltration, natural ventilation, and mechanical ventilation.**
6. **What is a fresh air connection? Evaporative cooler? Heat recovery ventilator?**
7. **What indoor air problems can result from a heat recovery ventilator?**
8. **What is the difference between a panel filter and a HEPA filter?**

LESSON 6
INDOOR AIR QUALITY MEASUREMENTS

During the past few years technological advances have resulted in the ability to detect ever smaller concentrations of contaminants with equipment that is increasingly user friendly and compact. However, the measurement of indoor air contaminants remains an undertaking that requires careful thought and preparation in order to ensure that data of high quality will be collected. An investigator's development of expertise in the measurement of indoor air contaminants depends on an understanding of the basic principles of the measurement process including options for sampling and analysis, sources of error, and quality assurance. Detailed information on specific methods and equipment is provided in Section 6 of the Reference Manual.

LESSON OBJECTIVES

At the end of this lesson you will be able to:

- **identify different options for equipment used to monitor indoor air contaminants;**
- **identify sources of error in the measurement process and ways to minimize errors; and**
- **describe important components of a quality assurance program.**

TYPES OF MEASUREMENT METHODS *(RM 6)*

The term "measurement" is a broad term that encompasses the measurement of air contaminants; physical parameters such as temperature, humidity, atmospheric pressure, ventilation rates, and air exchange rates; characteristics of the buildings being investigated; and the health and activity patterns of occupants. This lesson focuses on the measurement of air contaminants.

Before indoor air contaminants can be characterized they must be collected and analyzed. **Measurement method** describes the overall procedure that is used (sampling plus analytical method). **Sampling method** is a term that describes the collection of the air contaminant; these methods and the equipment used for collection (samplers) do not analyze the data. Sampling methods can be active (pumps move air) or passive (air movement by diffusion). **Analytical method** refers to the chemical method that is used to identify and quantify the contaminant. **Monitoring method** refers to measurement methods in which electronically-based equipment is used to both collect and analyze the air contaminant. Active or passive methods can be used to deliver air to the detector, but a power source is typically required for analysis. In this lesson, the terms sampling equipment and samplers will also be used to refer to monitoring equipment and monitors.

Measurement methods can be direct or indirect reading. Direct reading methods are those in which sample collection and analysis are accomplished in one step; the results are determined as the sample is collected. Many of these methods are electronically based in which a sensor detects an input signal that is converted by mechanical and electrical components into a concentration or other measurement that can easily be interpreted. Other direct reading methods rely on colorimetric indicators to react chemically with a contaminant to produce a color change which can be interpreted according to a calibrated scale. Although most direct reading methods require moderate to large capital expenditures, they can be economical if many analyses are required (for example, in routine sampling for carbon monoxide, carbon dioxide, radon, particulates, and other contaminants).

Indirect reading methods are those in which sampling and analysis are accomplished in two steps. The sample is collected onto or into a substrate which undergoes a separate analysis, typically in a laboratory. Particulates can be collected onto a filter and gases can be collected into a liquid or onto solid chemicals or chemically treated papers. Some indirect reading analytical methods such as the gravimetric analysis of particulates are relatively moderate in cost (about $25 for each gravimetric analysis), but other methods such as gas chromatography and/or mass spectroscopy for gases can be very expensive ($200-$300 per sample analyzed). If the costs for sampling and analysis are combined, these methods can be characterized as moderate to expensive.

Measurement methods can also be grouped according to required sampling times, portability, presence of an air mover system, and collection and analytical methods. Section 6 of the *Reference Manual* contains a summary of indoor air sampling equipment with information on these and other parameters including lower detectable limits, sampling rates, estimated prices, weight, and dimensions. The final selection of equipment will depend on operating and performance specifications, labor requirements and costs which are outlined in Table 6-1.

Sampling Time

Based on the length of time a contaminant is measured, sampling equipment (and monitoring equipment) can be classified as continuous, integrated, or grab.

Continuous samplers provide a real-time record of contaminant concentrations. The equipment can provide very reliable data, but it is generally

Table 6-1. Factors to consider in the selection of measurement methods and equipment.

Measurement Objectives:	screening or in-depth
Operating Specifications:	size; weight; power source requirements; range; flow rates; heat output; temperature requirements; exhaust requirements; noise
Performance Specifications:	accuracy; precision; range; minimum detectable limits; zero and span drift; interferences; linearity; recording capability; lag, rise and fall times
Labor Requirements:	operation; calibration; maintenance; analysis; personnel (number and expertise)
Costs:	purchase of equipment and supplies; operation; calibration; maintenance; training

References that provide useful descriptions of equipment include Lioy (1983); Nagda and Rector (1983); Nagda, Rector and Koontz (1987); and Wallace and Ott (1982).

expensive, time intensive, and requires extensive training to use.

Integrated samplers provide an average concentration over a period of time ranging from minutes to weeks to months. Some samplers can provide data sequentially in an automatic mode without needing a technician to change parameters. One disadvantage of integrated methods is that concentration highs and lows are lost. Equipment for integrated methods is low to moderate in cost and some training is required for use, but the required training is not as extensive as for continuous methods.

Grab samplers provide a concentration measurement at a single point in time. The equipment is inexpensive to moderately expensive, depending on the number of samples to be taken. Minimal training is required, but the data are not very reliable.

Portability

After the required time frame for sampling has been identified, sampling equipment can be selected based on the need for mobility or spatial variation. Based on this criterion, equipment can be classified as stationary, portable, or personal.

Stationary samplers operate from a fixed location. The equipment is generally bulky, heavy and requires a power source. Continuous samplers are usually stationary.

Portable samplers are small enough to be conveniently carried from place to place. Most equipment uses batteries for power, but some also has the option of using direct current. Integrated and grab samplers are typically portable, but some continuous equipment can also be portable. (Note: Batteries should be removed from battery-operated samplers when not in use to ensure proper charge, especially when a battery level indicator is not present.)

Personal samplers are lightweight, quiet, and can easily be carried or worn by a person. Although personal samplers may be preferred for many sampling problems, they are not available for all contaminants. If personal samplers are not available, portable methods are usually favored over stationary methods because they are generally less expensive and easier to use.

Air Mover Systems

Air mover systems, which are classified as either active or passive, transport contaminated air into the air sampling measurement device. Particles and gases can be sampled using either system.

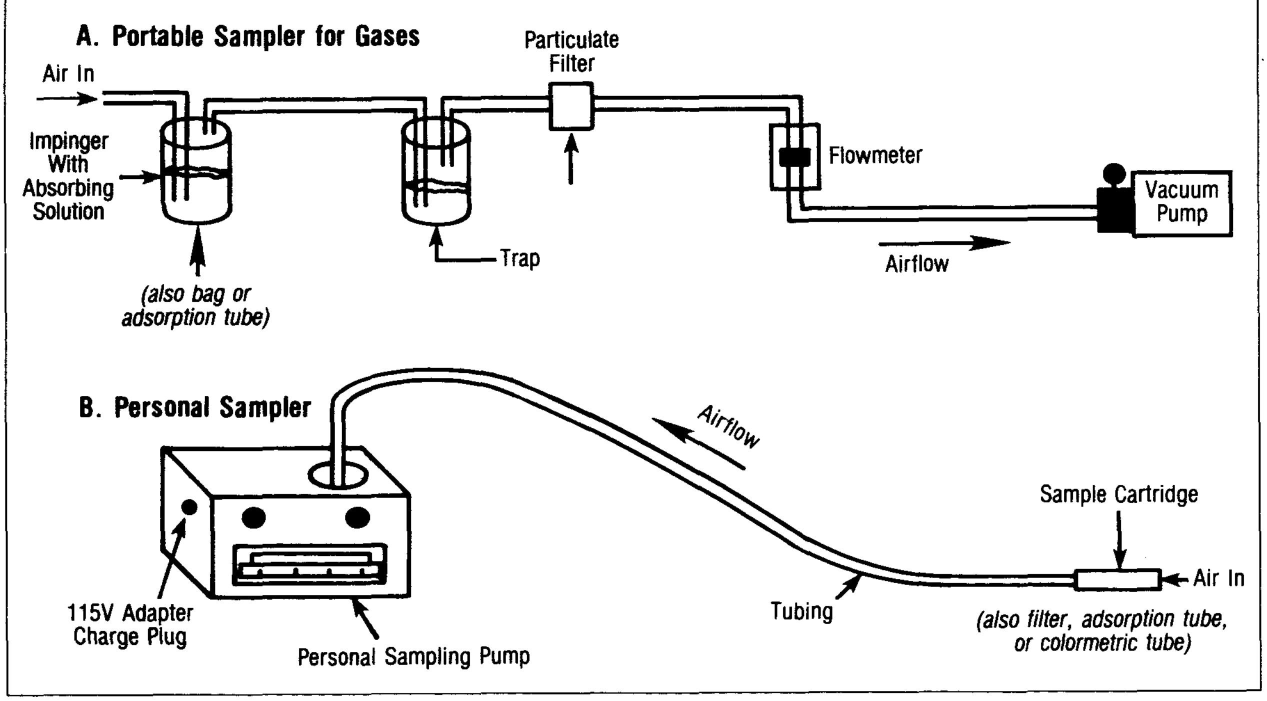
Active Samplers

Active samplers (Figure 6-1) use an air mover system powered by a pump to draw the contaminated air through a collector or sensor. Continuous, integrated, or grab samples of gases or particles can be collected; these samples can be analyzed on-site or taken to a laboratory for further processing. The volume of air moving through an active sampler and the resulting concentrations can be determined more accurately than with passive samplers. On the other hand, these samplers require more training than passive samplers, and they are also noisier and bulkier.

Active samplers range in complexity from simple bellows and piston pumps which are used with colorimetric tubes or dosimeter badges to mass flow controlled direct reading instruments.

The personal sampling pump is an active air mover system that is widely used in indoor air measurements. These compact battery-operated units can handle flow rates from 1 ml/min to 4500 ml/min. They are easy to operate, require minimal training, and can sample a broad range of contaminants using adsorption tubes, filters, bubblers, colorimetric tubes, and air bags to collect the contaminant for further analysis.

Figure 6-1. Examples of active samplers.



Passive Samplers

Passive samplers (Figure 6-2) do not have pumps to move the air through the sampling device; rather, contaminants diffuse or permeate through the collecting medium. Contaminant concentrations can be read directly or further analysis may be required. These samplers have the advantages of being lightweight, compact, and inexpensive for single samples. They are easy to use and require little or no training. They are good for initial screenings, and are commonly worn by an individual to estimate personal exposures. Disadvantages include decreased sensitivity and limited accuracy (usually ± 25% or more). Passive samplers provide integrated data rather than real time data. If the sampler is not direct reading, the additional time required for analysis may be a drawback to its use. Section 6 of the Reference Manual provides a summary of some passive sampling methods.

Collection Methods

Particles and Aerosols

Particles and aerosols can be sampled using filtration, inertial, gravity, electrostatic, or thermal collectors. Section 6 of the Reference Manual summarizes some commonly used collection methods for asbestos, other fibers, inhalable particulates, and metals. Filtration and inertial collectors have been the most widely used methods because of ease of use, low cost, and broad applications.

Filtration is a technique in which filters are used to collect particles which are subsequently analyzed for metals, organic compounds, fibers, microorganisms, and radon progeny. The choice of filter type in a given situation depends on the general characteristics of the filter, background filter impurities, flow resistance over time, collection efficiency, ease of analysis, cost, and availability. A wide variety of filters is available including cellulose, glass fiber, membrane, and nucleopore. Interest in collecting respirable particles (those that are 10 microns or less in diameter) has resulted in the increased use of inertial collectors. These collectors can separate particles in the gas stream according to particle size using impaction, impingement, or centrifugal force.

Gases and Vapors

Gases and vapors can be collected using both active and passive systems with two basic collection techniques: 1) collection into a suitable container such as a bag, bottle, or canister; and 2) removal from the air and concentration by adsorbing or absorbing the gas onto a solid or into a liquid solution.

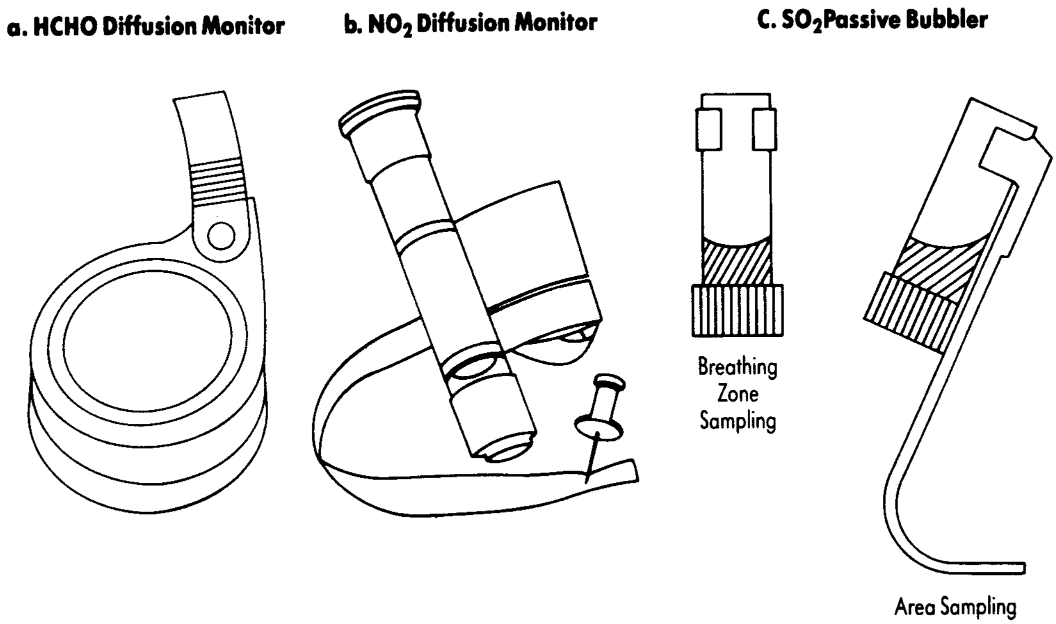
Plastic sampling bags can be used for collecting integrated samples for periods ranging from instantaneous samples to 8-hour samples. Samples can remain stable for hours to several days. Some common bag materials include Mylar®, Teflon®, and polyethylene.

Absorption is a process in which gases are transferred into a liquid or solid medium in which they dissolve. The concentration of the gas that is dissolved in the liquid or solid increases until an equilibrium is established with the concentration of the gas in the air. Continued sampling past this point will not increase the concentration of the gas in the solution.

Adsorption is a method of collecting gases in which the gas is attracted to, concentrated in and retained on a substrate. After the gas has been collected, it can be removed from the adsorbent for analysis by treatment with chemicals, heat, or inert gases. Solid sorbents have been used to determine volatile organic compounds in indoor air; activated charcoal has been a commonly used sorbent in passive and active samplers. Other adsorbing agents include activated alumina, silica gel, and porous polymers (Tenax-GC, Chromosorb, Porapak Series, Amerlite XAD-2).

Solid sorbents can provide an integrated sample of varying time (typically 8-12 hours), and because of

Figure 6-2. Examples of passive samplers.



a. ©3M Occupational Health and Safety Products Division. With permission.
b. Air Quality Research International. With permission.
c. Air Technology Labs. With permission.

the small size of sampling tubes and pumps, they are easy to use in a variety of indoor situations.

Analytical Methods

The number of analytical methods available for identifying and quantifying contaminants and physical stressors can be overwhelming. Most indoor air quality investigations will be handled by relatively few methods, but it is useful to have an awareness of other methods that could be used in special circumstances.

Physical Stressor Detectors

Temperature: Room air temperature can be measured by liquid-in-glass thermometers (alcohol or mercury), resistance thermometers (platinum, thermisters), thermocouples, and bimetallic thermometers. Analog thermometers can be purchased for less than $10, and the cost of digital thermometers is about $35 to $100.

Humidity: Humidity is commonly measured as the relative humidity which is the ratio of the amount of water vapor in the air at a specific temperature to the maximum amount of water vapor that the air could hold at that temperature. Relative humidity can be measured using hygrometers or psychrometers.

Analog hygrometers can be purchased for as little as $35; digital units that can also measure temperature and are traceable to the National Institute of

Standards and Technology (NIST), formerly the National Bureau of Standards (NBS), can be purchased for about $200. (See discussion below under *standard materials*)

The sling psychrometer has a thermometer holder that telescopes into a swivel handle which has a slide rule that contains scales for relative humidity and wet- and dry-bulb temperatures. The psychrometer is whirled by hand to produce the air velocity required to determine the wet-bulb temperature which is needed along with the dry-bulb temperature to read the relative humidty. Sling psychrometers can be purchased for about $75. A powered psychrometer can be purchased for about $350, but this level of expense is not needed.

Light: The intensity of visible light can be measured using light meters. These meters measure the quantity of light per unit area in foot-candles (ft-c). Light meters can measure light intensities over a broad range (from 0 to 99,900 ft-c). Analog meters can be purchased for about $100 and digital meters can range from about $150 to $300, depending on the range of light to be measured and whether the meters are traceable to NIST.

Air Motion: In most situations air movement can be measured using analog or digital meters and smoke tubes. When using meters to measure air motion it is important to use devices that are nondirectional or to monitor the orientation of the meter carefully to ensure that the true air speed is being measured.

Air velocity can be measured in rooms or inside heating and ventilating ducts, grilles, and diffusers. The unit of measurement for air velocity is feet per minute (fpm) or meters per second (mps). Some meters also contain scales for measuring static pressures in ducts. A mechanical air velocity meter kit that can measure velocities, and differential pressures at a variety of locations costs about $1000. Mini-sized air velocity meters, which can measure the same air velocity range but not static pressures, can be purchased for about $250 to $500. These mechanical systems do not require power sources or batteries.

Direct readings of airflow [in cubic feet per minute (cfm) or cubic meters per second (cms)] can be obtained with air volume meters. Standard-sized units cost about $1700 and mini-sized meters cost about $1000. Both units have hoods of different sizes which fit directly over supply and exhaust openings that channel the air through a manifold to a specially designed base that senses airflow and averages the results. A wide range of flows can be measured (0 to about 2000 cfm).

Smoke tubes or smoke candles release visible smoke which blends readily with air to aid in observing airflow. These devices should be used cautiously because they can trigger fire alarms and the smoke can be irritating. Smoke tubes or candles can be purchased in different sizes depending on the amount of smoke to be generated. Costs are about $2 to $7 per tube or candle.

Noise: There is a variety of equipment available for measuring noise. For most evaluations, the sound level meter (A-weighted scale) will provide sufficient information. In some instances an octave band analyzer may be needed. Meters with the A-weighted scale only can be purchased for about $300; an acoustical calibrator (about $200) must also be purchased. Meters that have more capability are slightly more expensive.

Particle and Aerosol Detectors

Particles and aerosols are most commonly collected onto a filter medium and the analyzed gravimetrically or by other methods, but instruments are available which can provide a direct reading of particles without an intermediate step. These instruments are relatively complex and expensive (from $500 to over $10,000). They operate by sensing some property of the particulate such as size, electrical charge, or mass.

Instruments for measuring particulates can be grouped into four categories: optical detectors, piezoelectric detectors, beta attenuation detectors, and electrical detectors. Optical detectors can be useful in routine indoor air quality investigations. The other techniques are probably more appropriate in outside air quality, occupational, or research investigations.

Optical detectors are based on the interaction of particles with light. These instruments can determine particle size and number. Particles in the size range from 0.5 to 10 microns can be detected with single particle detectors. Instruments which can analyze fibrous aerosols, including asbestos, are also available.

Gas and Vapor Detectors

There are many instruments that can detect contaminants in the gaseous phase at the same time they are being sampled. Although they are more expensive than indirect reading methods (typically, several thousand dollars to over $10,000) and require skilled operators, they may be cost effective for contaminants which are routinely measured.

Some situations such as the investigation of faulty furnaces or gas leaks require direct reading instruments. In other situations, the convenience of a direct reading is attractive because it eliminates potentially lengthy turnaround times in a laboratory.

In general, there are seven analytical methods that can be applied to the analysis of gases and vapors (Nader, Lauderdale, and McCammon, 1983). These methods are electrical, electromagnetic, chemi-electromagnetic, thermal, gas chromatography, magnetic, and radioactive. They can be incorporated into direct reading field instruments or laboratory-based instruments and techniques. They are described in Section 6 of the *Reference Manual*.

Direct Reading Colorimetric Indicator Devices

One of the most commonly used techniques for gases (and some particulates such as lead) is the colorimetric indicator device. These devices, which can be active or passive, are widely used in industrial hygiene and emergency response applications to sample contaminants at relatively high concentrations (in the range of the OSHA standards). This technique is generally inadequate for indoor air monitoring because of the lack of specificity of some tubes and accuracy. Nevertheless, there may be some instances when these devices can be usefully employed.

These devices rely on the chemical reaction between a contaminant and a reagent to produce a color which can be interpreted visually or optically. They may consist of liquid reagents, chemically treated papers, and glass indicating tubes containing solid chemicals. The color changes can be observed as a length of stain on a calibrated tube or a color change in a tube or badge which is compared to a standard color chart.

If these methods are used, cautions should be observed. Devices should be refrigerated, stain fronts or color changes should be read immediately after sampling, and pumps should be checked for leaks and calibrated regularly. And, most important, the accuracy and lower detectable limits should always be foremost in the mind of the investigator when selecting these devices and interpreting results.

MINIMIZING ERRORS *(RM 6.2, 6.3, 6.4)*

Sampling Protocol

One important way of minimizing errors is to develop a sampling protocol or written plan before sampling begins. The protocol is a valuable tool which can ensure that the measurement problem has been thought-out, and that time, money, and resources will be optimized to provide quality data. The protocol should include basic information such as what will be sampled and how, where, when, and by whom the sampling will be accomplished. A key component of the protocol is the evaluation of data reliability through the use of a quality assurance plan.

The selection of appropriate equipment, and the proper operation, routine maintenance, and calibration of equipment are critical to the success of any sampling program. Calibration is a check on the sample collection system and the analytical method to verify that accurate measurements are made. It is the cornerstone of any sampling protocol and can make or break the validity and usefulness of the collected data.

It is the investigator's responsibility to know each piece of equipment or method that will be used and to identify maintenance and calibration requirements before sampling begins. Maintenance and calibration schedules should be delineated in the protocol and followed strictly.

Instructions should also be included on sample handling, storage, and transport. Directions for calculations and criteria for accepting data should also be included in the protocol along with other quality assurance procedures. In developing the protocol, it is a good idea to seek advice from both a chemist, industrial hygienist, or other person who has expertise with the proposed analytical methods and a statistician, if the project involves multiple locations or measurements. If the sample is to be collected and then analyzed at a later time in the laboratory, the investigator must also be sure that the laboratory personnel follow a quality assurance program.

A major objective in designing a sampling program is to collect a representative sample--one that reflects the exposure that is being experienced. This requires careful attention to sample size and selection of methods (Section 6 of the *Reference Manual*). Failure to collect a representative sample can be an important source of error in any investigation.

Quality Assurance

Quality assurance (QA) describes the activities needed to provide assurance that high quality data are being collected. The objectives of a quality assurance program are to ensure that the data are accurate, precise, complete, representative, and comparable. Factors in a quality assurance program include:

1) adequately trained and experienced personnel;

2) proper equipment and facilities in good working order;

3) written sampling, calibration, and maintenance procedures and schedules;

4) data validation programs;

5) chain-of-custody procedures; and

6) a supportive management team.

Quality control refers to that part of the quality assurance plan that directly measures data reliability through calibrations and other checks such as blanks and duplicates.

Ideally, a good indoor air quality sampling program will have a written plan that incorporates as many of the components of an ideal quality assurance program as possible. Although such a plan may not be required, it is sound practice to develop and use as many of the components as feasible. Additional information on the elements of quality assurance programs for quality measurements are discussed in EPA ambient air quality assurance documents (U.S. EPA 1975, 1977, and 1980) and in the compendium of methods for indoor air (U.S. EPA, 1989).

An example quality assurance plan for indoor environments is given in GEOMET Technologies, Inc. (1985).

Accuracy and Precision

All measurement methods are subject to error. Accuracy and precision are two measures of data quality that help evaluate errors in the measurement process (Section 6 of the *Reference Manual* discusses each in greater detail). Accuracy is a measure of how close data points are to the true result, and precision describes the variation or scatter among the results (Figure 6-3). Precision is a measure of the uncertainty of the average concentration--it is not related to the true concentration.

Accuracy is affected by sources of error that can be identified and controlled. These errors are known as systematic errors because they result in measured values that are consistently above or below the true value. Systematic errors can arise from many sources including errors in calculation, incorrect calibrations, contaminated reagents, interferences, improper operation of equipment, and improper handling and storage of samples. Systematic errors cannot be treated by statistical methods.

Precision is affected by sources of error that are random and cannot be controlled. Sources of random error include variations in equipment such as airflow fluctuations, variations in the contaminants being tested, and variation in the analytical methods, including instrument responses. Random errors can vary in magnitude and direction, and they are never completely eliminated. Random errors can be accounted for and minimized by statistical techniques. For example, random errors can be minimized by increasing the size of the sample.

Ideally, the sampling or analytical method that is employed will be both accurate and precise. However, it is possible for a method to have high precision, but low accuracy because of improperly calibrated equipment or inaccurate measurement techniques. Alternatively, a method can be accurate, but imprecise, because of low instrument sensitivity or factors beyond the investigator's control.

Interferences

Interferences are chemicals or factors other than the contaminant of interest which react during sampling or analysis to give concentrations that are higher or lower than the true value. Interferences can result in significant sampling errors and must be considered before a sampling method is selected. Most standard methods and equipment specifications identify major interferences.

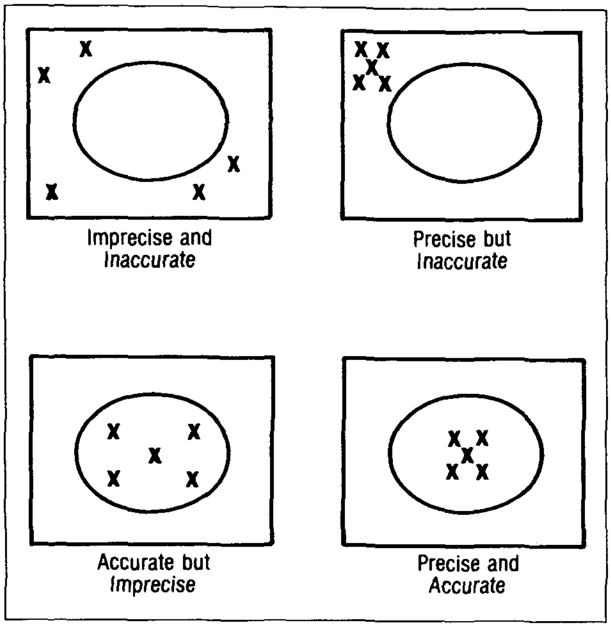
When standard methods are not used, it is important to review the literature to obtain information on potential interferences. The potential impact of interferences on the data can be estimated, and then a decision can be made to try another method, ignore the interference, or correct for the interference. Ignoring interferences and correcting results are common practices, but they should be approached cautiously.

Reporting only corrected results obscures information that affects the validity of the data. For example, data that have a 5% correction factor for interferences will likely be viewed differently than those that have a 25% or 50% correction factor. If correction factors are applied, they should always be reported along with the data.

Limit of Detection and Limit of Quantification

The limit of detection (LOD) is the smallest quantity or concentration of a contaminant for which an analytical method will show a response. The limit of quantification (LOQ) is the smallest quantity or concentration that can be quantified in an environmental sample.

Figure 6-3. Accuracy and precision.



SOURCE: Adapted from *The Industrial Environment - Its Evaluation and Control.* C.H. Powell and A.D. Hosey. (eds). 1965. Health Services Publication No. 614. U.S. Dept. Health, Educ., and Welfare: Cinncinati, OH.

Blanks, Duplicates, and Standard Materials

Blanks: The term "sample blank" refers to the concentration of a contaminant that is present in the medium (chemical, filter) that is used to collect the sample. For example, if radon is sampled using track-etch detectors and all samplers are deployed, it will not be possible to know if there is any contamination of the sampler. However, if a number of samplers are held back and remain sealed and unexposed, then they can be sent back to the laboratory and analyzed, allowing any contamination to be detected. The value of the sample blank should always be subtracted from the measured concentration. If the blank concentration is greater than the measured concentration, the collected data should be regarded as invalid.

About 10% of the total number of samples collected should be blanks, and at least one blank should be included in each measurement batch.

Duplicates: Duplicate samples are those which are collected and handled in exactly the same way as the regular samples. Duplicate samples should be collected for indirect reading methods and some direct reading methods. The use of duplicate instruments for direct reading methods is usually reserved only for research applications when the method is being investigated.

Duplicate samples provide an additional check on the quality of the data, and they should agree very closely with one another. A useful guideline is to have duplicates for about 10% of the total number of samples collected.

Standard Materials: Standard materials are those for which purity and concentration have been verified by an outside agency. NIST, EPA, and NIOSH all provide standard materials that can be used in the calibration of equipment and laboratory analytical methods. Section 6 of the *Reference Manual* contains a list of materials which can be obtained from NIST; a list of the EPA's regional Quality Assurance Offices which can be contacted to obtain more information about standard materials is also included. EPA does provide, at *no charge,* cylinders of standard gases, including hazardous organic compounds, that may be used to audit the performance of indoor air measurement systems.

Calibration

Calibration is the establishment of a relationship between various standard materials and the measurements of them obtained by all or part of a measurement system. The levels of standard materials which are used should bracket the range of levels for which measurements will be made.

In the case of direct reading instruments, calibration standard materials (calibration standards) are used to quantify the relationship between the output of a sensor and contaminant concentrations. This relationship allows the user to know that the instrument is responding accurately (or inaccurately) to contaminants in the air.

Without proper calibration of equipment and methods, the sampling results cannot be assumed to be accurate and reliable. Considerable money and time can be wasted in the long run when investigators skimp on calibration.

Sampling pumps, flowmeters, analyzers, calibration gases, and laboratory analytical procedures must all be calibrated. It is essential for any chemical reagents or gases that are used in the calibration to be of the highest reliability. This means they must be certified in some manner; materials that are traceable back to NIST will provide the highest reliability.

The frequency of calibration varies depending on the requirements of data acceptability, performance between scheduled calibrations, and manufacturer's recommendations. The conditions under which the instruments are used and the number of people using the instruments and their skill levels should also be considered. A general rule is to calibrate before and after each sampling period if equipment is turned off or transported between measurements.

Methods of calibration for equipment and laboratory methods are specified in EPA methods and several references (Taylor, 1987; Katz, 1977; and EPA, 1977; 1989; NIOSH, 1984); these should be used whenever possible. Section 6 of the *Reference Manual* contains more information on the calibration of equipment.

Proficiency Testing

Proficiency testing is an external quality control check that involves the analysis of reference samples once or twice a year. Certified samples are sent to laboratories for analysis. The laboratory's performance is judged by the accuracy of the analysis. Proficiency testing is a commonly used technique in industrial hygiene and environmental analysis. It provides additional assurance about the quality of the data produced by laboratories.

Proficiency testing is not routinely available in indoor air quality work; however, programs do exist for the measurement of radon and asbestos. These programs are administered by EPA, and EPA publishes a list of companies that pass the performance tests. Selecting a company that passes the proficiency test provides additional assurance that quality data will result. EPA also provides comparison standards (audit materials) for the compendium methods through the Atmospheric Research and Exposure Assessment Laboratory, Quality Assurance Division, MD-77B, Research Triangle Park, NC 27711.

Validation of Collected Data

The validation of data is a final critical point in the measurement process, and the investigator should have a set of criteria by which to judge the validity of collected data. These criteria should include the following:

1) instruments should operate properly during sampling periods (if an instrument or pump is not operating at the end of a designated sampling period, the data collected during that time period should not be used);

2) analysis of blanks and duplicate samples, and calibrations must be performed properly and be within pre-determined limits during the times the data were collected;

3) extreme values must be checked to determine causes;

4) calculations and data transfers must be performed properly; and

5) results should be evaluated to determine if they are consistent with other measurements.

In general, it is best to flag data which are outside the designated data validation criteria. Data which do not meet the designated acceptable criteria, with few exceptions, should not be included in statistical summaries. There is a real temptation to rationalize the inclusion of data that are outside the designated data validation bounds because of the effort that goes into data collection, but this should be resisted. Report only those data in which there is confidence.

There are instances when data will be useful in a qualitative evaluation even though they may not pass all of the validation criteria. If data that have not met the inclusion criteria are included in a report, be sure to flag them for the reader, clearly pointing out the problems and deficiencies.

Always keep in mind how data will be used. Will a decision about a health risk be made? Will a policy decision be made? If the data are to be used for critical decisions, it is far better to repeat measurements and incur the extra expense, rather than including lesser quality data that may have far-reaching consequences. The investigator must exercise careful judgment in deciding the validity of data.

Data that are within pre-designated acceptable criteria but are either much higher or lower than other measurements should be included in the data summary. Statistical tests can be applied to determine if a value is an "outlier," but even when outliers are verified statistically, they should be included in the report of the data. Under no circumstances should data arbitrarily be excluded from a report simply because they do not fit the mold. If, after careful evaluation of the entire sampling process, no reason can be found to exclude the data, they should be reported as valid. However, outliers may be treated differently in the analysis and interpretation of data.

STANDARD METHODS *(RM 6)*

Standard methods or procedures do not currently exist for the measurement of all indoor air pollutants, but EPA has developed 21 methods for 9 categories of contaminants plus two methods for determining air exchange rates (U.S. EPA, 1989). In addition, there are some ambient air quality and industrial hygiene procedures which are suitable for indoor air quality investigations.

EPA's Compendium of Methods for Indoor Air

In response to the need for specific guidance on the determination of indoor air contaminants, EPA has developed methods for the determination of selected contaminants in indoor air. However, EPA cautions that these methods at this time are not certified and are not officially recommended or endorsed by EPA. The following methods have been developed:

1) volatile organic compounds using summa® stainless steel canister sampling or solid adsorbents;

2) nicotine using XAD-4 solid adsorbent, active filter cassettes, or passive filter cassettes;

3) carbon monoxide and carbon dioxide using nondispersive infrared spectroscopy or gas filter correlation;

4) nitrogen dioxide using continuous luminox LMA-3, Palmes diffusion tube, passive sampler badge, or a transducer technology electrochemical technique;

5) formaldehyde using solid adsorbent Sep-PAK 2,4-DNPH cartridge, passive sampler badge, or a continuous CEA monitor;

6) benzo(a)pyrene and other polynuclear aromatic hydrocarbons in air using a combination quartz filter/adsorbent

cartridge with subsequent analysis by gas chromatography with flame ionization and mass spectrometry detection or high performance liquid chromatography;

7) selective pesticides using low volume polyurethane foam sampling with gas chromatography/electron capture detector;

8) acid, bases, aerosols, and particulate matter using an annular denuder coupled with filter pack assembly or transition flow reactor;

9) particulate matter using an impactor with filter pack assembly or a continuous particulate monitor; and

10) air exchange rate using perfluorocarbon tracer or tracer gas.

Whether or not a specific method will be appropriate for a given application will depend on economic resources, available expertise, and the application itself. Not all methods will be appropriate or possible for routine sampling applications.

Information on the EPA methods can be obtained from the EPA Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC 27711.

Canadian Indoor Air Test Kit

The Building Performance Division of Technology, Architectural and Engineering Services within Public Works Canada has developed an indoor air quality test kit (Public Works Canada, 1988) which is intended to be simple, easy to use, and require little technical training. This kit includes an investigation strategy that begins with a preliminary assessment followed by measurements with simple instruments and complex instruments, if needed.

Step-by-step instructions are contained in the test kit which includes equipment for measuring carbon dioxide, carbon monoxide, formaldehyde, radon, volatile organic compounds, relative humidity, temperature, and air movement.

More information about this kit can be obtained by contacting the Architectural and Engineering Services Division, Public Works Canada, Sir Charles Tupper Building, Riverside Drive, Ottawa, Ontario, K1A OM2.

NIOSH Analytical Methods

The National Institute for Occupational Safety and Health (NIOSH) publishes a manual of analytical methods that includes 350 methods for over 600 substances (NIOSH, 1984). However, these methods were developed for the industrial environment, and many of the substances are not relevant for other indoor air quality problems. Nevertheless, some of the methods, particularly those for formaldehyde and volatile organic compounds are used successfully by NIOSH in investigating nonindustrial workplaces. The manual is available from the U.S. Government Printing Office.

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PROGRESS CHECK

1. Briefly explain the classification of measurement methods according to sampling times, portability, and air mover systems.

2. What is the most common method of collecting particles?

3. Explain two general methods of collecting gases.

4. What are some drawbacks to using colorimetric detector tubes?

5. Identify different detection methods and/or instruments for sampling particles, gases, and physical stressors.

6. Briefly explain what is meant by sampling protocol, quality assurance program, and standard methods. Why are these important?

7. Briefly explain the terms precision, accuracy, interference, LOD and LOQ, blanks, duplicates, standard materials, and calibration.

8. What are some general guidelines for evaluating the quality of data?

LESSON 7

STANDARDS AND GUIDELINES FOR INDOOR AIR CONTAMINANTS AND VENTILATION

Standards and guidelines were discussed in Lesson 5 as one of the policy tools available to both government and private sector organizations to control indoor air quality. This lesson summarizes standards and guidelines, and discusses their applicability to indoor air quality.

LESSON OBJECTIVES

At the end of this lesson, you will be able to:

- identify and discuss the primary public health and occupational air quality standards and guidelines;
- identify and discuss the primary ventilation standards/guidelines;
- identity the primary building code provisions that affect indoor air quality; and
- understand the strengths and weaknesses of existing standards and guidelines.

AIR QUALITY STANDARDS AND GUIDELINES
(RM 7)

Air quality standards and guidelines specify maximum concentrations and exposure times for specific contaminants for indoor and outdoor environments. They are designed to protect specified classes of individuals from adverse health impacts. Different standards are designed to protect different classes of individuals, and to different degrees, depending on the nature and purpose of the standards.

There are two broad types of standards and guidelines: public health standards and occupational standards. Public health standards are designed to protect the general public, and are therefore most applicable to residential, educational, commercial, and public building environments. Occupational standards, on the other hand, are designed to protect workers, and are generally applied to industrial work environments.

Public health standards are generally one to two orders of magnitude lower (more protective) than occupational standards for several reasons.

- Occupational standards protect healthy adult workers while public health standards are designed to protect all segments of the population, including potentially sensitive subgroups--the elderly, infants and children, pregnant women, and those with preexisting heart and lung diseases.
- Occupational standards protect workers for limited periods of time (usually the 8-hour work day) while public health standards generally protect the public for continuous lifetime exposures (24 hours/day).
- Occupational standards factor cost and technical feasibility into the recommended limits while public health standards are often established without regard to cost or feasibility.

In the United States there are no Federal standards that have been developed specifically for indoor air contaminants in nonoccupational environments. There are related existing standards and guidelines that can be used for some comparisons, but most of these are not directly applicable to indoor air quality problems.

The limited inventory of public health standards and guidelines for most of the contaminants commonly found in indoor environments complicates the interpretation of data. Occupational standards are sometimes divided by an arbitrarily selected protection factor (somtimes 10 to 1000), and the resulting number is used as a benchmark for evaluating indoor environments. This practice is ***not*** recommended because these standards were not derived to protect the general population, and the application of protection factors can result in significant inconsistencies among contaminants. The resulting numbers may not provide sufficient protection, or they may be unduly restrictive.

In the absence of standards for specific contaminants, or in the face of several standards or guidelines for a single contaminant, good public health practice requires a conservative approach to the interpretation of measured data. If there are several published standards or guidelines for a particular contaminant, it is appropriate to use the lower end of the range for the interpretation of data. If there are no indoor air quality standards or guidelines, for a particular contaminant, a review of the literature can be useful along with obtaining advice from experts.

Setting standards for indoor air quality contaminants is in its infancy. Section 7 of the *Reference Manual* identifies contaminant levels and exposure times specified by organizations and government agencies which have published standards and guidelines. This lesson reviews these standards and guidelines in terms of their general concepts, terminology, and guiding principles.

Public Health Standards and Guidelines

Ambient Air Quality Standards

The EPA *National Ambient Air Quality Standards (NAAQS)* [U.S. EPA, 1989] apply to the outdoor air, and they are developed under the authority of the Clean Air Act. These standards are enforced by the states which may either adopt the Federal standards or promulgate more stringent standards. Standards have been developed for six contaminants (sulfur dioxide, nitrogen dioxide, ozone, lead, particulates, and carbon monoxide).

Primary standards are designed to protect human health and secondary standards are designed to protect the public welfare (buildings, crops and other vegetation, animals). The standards protect against short-term and long-term effects that might result from exposure to contaminants in the outdoor air.

Under the Clean Air Act, primary standards are to be developed with an adequate margin of safety to protect the public health without consideration of cost. Primary standards should also protect the most sensitive subgroups of the population (for example, asthmatics or those with chronic respiratory problems).

The required margin of safety is established by the Administrator of the EPA, and it can vary from contaminant to contaminant. When it establishes standards, EPA considers the uncertainty in the scientific information, the activity level of the exposed population, and to some extent the possibility of other exposure routes. These standards may not be directly applicable to indoor air environments because of differences in averaging times.

Air Quality Guidelines for Europe

The World Health Organization (WHO) *Air Quality Guidelines for Europe* is a compilation of air quality guidelines and summaries of the scientific evidence for 28 organic and inorganic substances (WHO, 1987). The major consideration in establishing the guidelines was health effects, but ecological guidelines are recommended for some contaminants. The guidelines include both short-term and long-term exposure limits designed to protect sensitive subgroups in the population.

For some contaminants, the guidelines provide an estimate of lifetime cancer risk arising from exposure to substances that are proven human carcinogens or substances for which there is at least limited evidence of human carcinogenicity. For other contaminants the guidelines identify concentrations combined with exposure times, at which no adverse noncarcinogenic effect is expected.

Canadian Exposure Guidelines

The Canadian *Exposure Guidelines for Residential Indoor Air Quality* were developed under the authority of the Minister of Health and Welfare by the Federal-Provincial Working Group on Indoor Air (Environmental Health Directorate, 1987). The guidelines contain specific quantitative limits for ten contaminants or contaminant categories (total aldehydes, carbon dioxide, carbon monoxide, formaldehyde, nitrogen dioxide, ozone, particulate matter, sulfur dioxide, water vapor, and radon). Recommendations are also included to eliminate or control exposure for other contaminants for which specific exposure limits were not practical. The guidelines were developed by evaluating human and animal studies. They include an Acceptable Long-Term Exposure Range (ALTER) which is based on a lifetime of exposure without undue risk to health and an Acceptable Short-Term Exposure Range (ASTER) which is based on exposures of varying time periods (5 minutes to 1 hour).

The guidelines are intended to ensure that there is "negligible" risk to the health and safety of occupants in residences; however, the Working Group notes that complete protection for the hypersensitive portion of the population may not be provided by the guidelines.

Occupational Standards and Guidelines

ACGIH Guidelines

The American Conference of Governmental Industrial Hygienists (ACGIH) is an association of occupational health professionals that is devoted to the development of administrative and technical policies for worker health protection. Through its technical committees, ACGIH regularly reviews the best available information from industrial studies, epidemiological studies, and animal studies to develop new limits and revise old ones.

ACGIH first published its limits, *Threshold Limit Values (TLVs)*, in 1968, and they are updated annually (ACGIH, 1989). The TLVs are concentration limits and conditions to which it is thought nearly all workers may be repeatedly exposed day after day throughout their working lifetime without adverse effects. However, because of the individual variation in response to chemical exposure, the ACGIH recognizes that a small percentage of workers may experience discomfort at levels below the TLVs, and an even smaller percentage may experience more serious effects such as aggravation of a preexisting condition or the development of an occupational illness at levels below the TLVs.

Some of the limits protect against impairment of health while others protect against irritation, narcosis, nuisance, or other forms of stress. Because of the increasing evidence that physical irritation can initiate, promote, or accelerate physical impairment, ACGIH states that limits based on physical irritation should be no less binding than those based on physical impairment.

ACGIH disclaims liability for the improper use of TLVs, and it specifically cautions that the limits are intended for use in the workplace and *not* for other uses such as the control of community air pollution nuisances, estimating the toxic potential of continuous, uninterrupted exposures, or as proof or disproof of an existing disease or physical condition. The ACGIH guidelines are recommendations; they are not legally binding.

Three categories of TLVs are defined.

- The *Time Weighted Average (TLV-TWA)* is the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek to which workers can be exposed day after day without adverse effect.

- The *Short Term Exposure Limit (TLV-STEL)* is the concentration to which workers can be exposed continuously for a short period of time without experiencing irritation, chronic or irreversible tissue damage, or narcosis to a degree that would increase accidental injury rates, or reduce work efficiency significantly. The STEL is defined as a 15-minute time-weighted average exposure which should not be exceeded at any time during a work day or occur more than 4 times each day. In addition, there should be at least 60 minutes between successive exposures at the STEL.

- The *Ceiling Limit (TLV-C)* is a concentration that should not be exceeded during any part of the working exposure.

OSHA Standards

The Occupational Safety and Health Administration (OSHA) is responsible for protecting workers from unsafe or unhealthy work environments. Standards for the workplace are promulgated by the Secretary of Labor under the Occupational Safety and Health Act of 1970 (U.S. DOL, 1989). These are mandatory standards.

The exposure standards for air contaminants are set at levels which will protect a worker from "material impairment of health or functional capacity" even if the worker is exposed for 8 hours per day for an entire working lifetime. The occupational health standards are based on a healthy adult worker; they do not take into account the variability of the general population.

The OSHA standards which encompass 600 chemicals were revised in 1989 (U.S. DOL, 1989). The first OSHA standards included *Permissable Exposure Limits (PELs)* which were the 8-hour time-weighted average limits developed by ACGIH in 1968. The revised standard essentially adopts the ACGIH guidelines for most contaminants, and it includes the TWA, STEL, and ceiling limits. Some of the new standards are more stringent than before and some have been relaxed.

The National Institute of Occupational Safety and Health (NIOSH) is part of the U.S. Department of Health and Human Services and it acts as the research institution for the Occupational Safety and Health Administration. NIOSH uses the most complete and current scientific information to develop and periodically revise recommended exposure limits to potentially hazardous substances or conditions in the workplace. The recommended exposure limits and supporting information are then submitted to the Department of Labor for consideration in developing PELs. NIOSH recommendations are published in criteria documents which can be obtained by contacting NIOSH.

SOURCE EMISSION STANDARDS

Source emission standards specify maximum rates at which contaminants can be released from a source. Source emission standards may be developed by governmental agencies such as the Consumer Product Safety Commission (CPSC), the Department of Housing and Urban Development (HUD), or by professional associations.

HUD has issued a product standard which limits the level of formaldehyde emitted from pressed wood products installed in mobile and manufactured homes. The HUD rule requires formaldehyde emissions not to exceed 0.2 ppm from plywood and 0.3 ppm from particleboard as measured by specified air chamber tests. (U.S. HUD, 1990a). The rule was established to provide indoor formaldehyde concentrations less than 0.4 ppm when the indoor temperature does not exceed 77°F, the relative humidity is less than 50%, the ventilation rate is at least 0.5 ach, and there are no other major emitters of formaldehyde in the home (U.S. HUD, 1984). The rule does not consider the carcinogenic potential of formaldehyde and other limits are more stringent.

Underwriters' Laboratories, CPSC, and the National Kerosene Heater Association are working together to develop limits for oxide of nitrogen emissions from unvented kerosene heaters; this standard however is not currently available.

VENTILATION STANDARDS *(RM 7)*

Ventilation standards specify minimum rates for the introduction of outdoor air into indoor spaces. The most widely used ventilation requirements are specified by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), a private standard-setting trade association, in ASHRAE Standard 62-1989. Other ventilation standards include model building codes, standards of HUD and the American Public Health Association (APHA) model housing code.

ASHRAE Standard 62-1989

ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality,* specifies minimum ventilation rates which are expected to be acceptable to occupants and avoid adverse health effects (ASHRAE, 1989). This standard was developed by an interdisciplinary committee, and it reflects a consensus opinion that attempts to balance the requirements of acceptable indoor air quality and efficiency in energy consumption. The standard applies to all indoor or enclosed spaces which people may occupy including residential and commercial spaces, classrooms, bathrooms, kitchens, locker rooms, swimming pools, and saunas. Acceptable indoor air quality is defined by ASHRAE as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction." However, ASHRAE recognizes the standard does not, and cannot, assure that no adverse health effects will occur.

Acceptable air quality can be achieved in two ways. The *Ventilation Rate Procedure* specifies the rate and quality of ventilation air which must be supplied to a given space, and it also specifies methods to condition the air. The *Indoor Air Quality Procedure* provides an alternate performance method in which acceptable concentrations of some contaminants are identified, but ventilation rates or air treatment methods to achieve those concentrations are not specified.

The Ventilation Rate Procedure

The ventilation rate procedure specifies minimum ventilation rates for about 85 types of residential, commercial, institutional, vehicular, and industrial spaces (Section 7 of the *Reference Manual*). In order to achieve these rates, the procedure specifies the quality of outdoor air used for ventilation. Acceptable outdoor air quality is basically air that meets the National Ambient Air Quality Standards; however, these standards include only six contaminants. If outdoor air contaminant levels exceed the NAAQS, the standard specifies that the air can be treated by filtering or other appropriate air cleaning devices.

The outdoor air requirement as defined by ASHRAE is 15 cfm or more per occupant for different spaces. For example, the office space requirement is 20 cfm per occupant. The outdoor air requirement for residential living areas is 0.35 ach but not less than 15 cfm per occupant. This is a level which should be met during all occupied periods and during all seasons. In kitchens, a rate of 100 cfm is required if intermittent exhaust ventilation is used and 25 cfm for continuous ventilation. The outdoor air requirement for baths and toilets is 50 cfm for intermittent ventilation or 25 cfm for continuous ventilation. Ventilation requirements in kitchens, baths, and toilets can be met with operable windows. The ASHRAE standard also specifies that the combustion system, kitchen, bathroom, and clothes dryer vents should not be exhausted into attics, crawlspaces, or basements.

The outdoor air requirement for residential garages is 100 cfm per car which is normally satisfied by infiltration or natural ventilation.

The Indoor Air Quality Procedure

This alternate procedure specifies minimum levels of indoor air contaminants as defined by generally accepted air quality standards and guidelines, but it does not specify ventilation rates or air treatment methods to achieve those levels. The contaminants which are specified within the standard include those identified in the EPA ambient air quality standards plus carbon dioxide, chlordane, ozone, and radon gas. ASHRAE also recommends that relative humidity in habitable spaces should be maintained between 30% and 60% to minimize the growth of allergenic or pathogenic organisms. In addition, Standard 62-1989 refers the reader to Appendix C which contains tables of standards and guidelines of contaminants which are used in the United States, Canada, and by the World Health Organization. Appendix C is not part of Standard 62-1989, but it is intended to provide guidance on acceptable contaminant levels for the indoor environment.

Other Ventilation Requirements

HUD Ventilation Requirements

HUD ventilation requirements are incorporated into its minimum property standards for residences (U.S. HUD, 1990b) which are part of its mortgage insurance and low rent public housing program and in construction requirements for manufactured housing (U.S. HUD, 1990c).

Ventilation for the construction of manufactured housing can be met in two ways. The rule specifies that an area equivalent to not less than 8% of the floor area must be available for natural ventilation (windows or doors), or alternatively, a mechanical system must be capable of changing the room air every 30 minutes (that is, 2 ach). Bathrooms and toilet compartments require either 1.5 ft^2 of openable glazed area or a mechanical system capable of producing 5 ach. The mechanical system must exhaust directly outside the house.

The rule for manufactured housing construction specifies the venting of combustion appliances and requires purchasers to be presented with options to improve overall ventilation. HUD is now considering ways to improve this standard.

Ventilation Requirements in Model Codes

Building codes identify design and construction specifications for buildings. The primary building codes that are in use in the United States include those written by the Building Officials and Code Administrators International (BOCA), the Southern Building Code Congress International (SBCCI), the Council of American Building Officials (CABO), and the American Public Health Association (APHA) model code.

These codes are updated periodically to reflect new knowledge and incorporate standards developed by other organizations. State and local governments can either adopt these codes in their entirety or revise them as needed. Sufficient time has not elapsed for these organizations to consider incorporating provisions of the new ASHRAE Standard 62-1989.

The ventilation requirements of the CABO and APHA codes are summarized as follows; relevant portions of the Uniform Building Code and additional CABO requirements are summarized in Section 7 of the *Reference Manual*.

The CABO One and Two Family Dwelling Code (1989 edition): The CABO code specifies ventilation requirements in habitable rooms as follows.

- All habitable rooms must have window space of not less than 8% of the floor area of such rooms and at least one half of the required area must be openable.

- Windows do not have to be operable if a mechanical ventilation system can provide 1 air change every 30 minutes (2 ach).

- Bathrooms, toilet compartments, and similar rooms must have window space of not less than 3 ft^2, one-half of which must be operable. The window space is not required if a mechanical ventilation system can provide a change of air every 12 minutes (5 ach). Bathroom exhaust must be vented directly to the outside.

- Crawl spaces must have enough ventilation openings to ensure ample ventilation; these openings should not be less than 1 ft^2 for each 150 ft^2 of crawl space area, and one opening should be within 3 ft of each corner of the building. The required space can be reduced to 1/1500 of the underfloor area where the ground surface is treated with an approved vapor barrier and one opening is within 3 ft of each corner of the building. The vents may have operable louvers.

- When a building official determines that attic ventilation is necessary, attics must have cross ventilation for each separate space. The net free ventilating area should not be less than a ratio of 1 to 150 of the area of the space ventilated. This can be increased to 1 to 300, provided that certain requirements are met.

APHA Model Housing Code: The APHA model code (Mood, 1986) also specifies ventilation air requirements. In the model code, ventilation requirements can be met in three ways: 1) each habitable room must have at least one window or skylight facing directly outdoors that can be opened easily, 2) the habitable room must be connected to a room or area used seasonally that provides adequate ventilation, or 3) some other devices can be used to ventilate the room adequately. The total operable window or skylight area in every habitable room shall be equal to at least 45% of the minimum window or skylight area which is 8% of the floor area of the room. The code also requires HVAC units which are integral to the structure to be operated continuously; if the unit becomes inoperable alternate provisions for ventilation are to be provided.

The code also contains a provision which requires ventilation, either natural or mechanical, to provide acceptable indoor air quality in every habitable room at all times when occupied. In addition, bathroom and kitchen exhaust air cannot be recirculated.

The model code does not specify numerical limits for indoor air contaminants. Instead, it defines acceptable indoor air quality as indoor air in which there are no known concentrations which are in excess of those which have been established by the Director of Health. This provision provides local jurisdictions with additional flexibility and control because the local health officer has the authority to declare a particular situation a health hazard and require remediation.

THERMAL COMFORT STANDARDS *(RM 7)*

Thermal Environmental Conditions: ANSI/ASHRAE Standard 55-81 specifies thermal conditions which will be acceptable to 80% or more of occupants in a building. Establishing appropriate thermal environmental conditions is important to minimize energy costs, maximize worker productivity, and minimize discomfort effects.

There are many factors which influence the perception of comfort, temperature, and thermal acceptability. Important environmental factors include temperature, radiation, humidity, and air movement; personal factors include clothing and activity level. Section 7 of the *Reference Manual* provides a summary of the acceptable ranges of temperature and humidity for winter and summer conditions. ASHRAE 55-81 also provides acceptable thermal conditions for different types of clothing, air movement, nonsteady state conditions (temperature cycling, temperature drifts), and nonuniform conditions (vertical temperature differences, radiant assymetry, floor temperatures). Some of these are summarized in Lesson 4.

SUMMARY AND CONCLUSIONS

Indoor air quality can be controlled through the development and implementation of air quality standards and guidelines, source emission standards, ventilation standards, and thermal comfort standards.

The development of standards and guidelines for contaminant levels indoors and sources of contaminants is still in its formative stages. More research is needed before comprehensive standards can be developed that specifically address indoor air quality concerns.

Inadequate ventilation is one of the major causes of indoor air quality problems, and ventilation standards are an important method of control. Problems, however, do exist in relying on ventilation standards in building codes as the sole protector of the public health. Some underlying problems are enumerated below.

- The current building stock has been constructed under different building codes with different requirements.
- The current codes may be dominated by energy efficiency considerations, and code requirements may not be sufficient to

provide adequate ventilation for indoor air quality purposes.

- There is no guarantee that builders follow current code requirements or that they did so in the past.
- Most jurisdictions do not have adequate inspection and enforcement capability to ensure that code requirements are followed.
- If energy efficiency measures have been employed that generally tighten buildings or exceed the designed capacity, inadequate ventilation may result.
- Even if newer buildings are designed to meet the most current ventilation standards, improperly operated and poorly maintained systems will defeat the design loads and reduce ventilation efficiency.
- Another problem in new construction is that ventilation requirements can be met using either operable windows or mechanical ventilation. New residential construction techniques that result in tight building envelopes without outdoor air intakes (in addition to combustion air) will be more likely to have indoor air quality problems because windows may not be used to provide outdoor air.

In spite of the inadequacies in both air quality contaminant and ventilation standards, these two approaches can be used to control indoor air contaminants in both old and new construction. New approaches, such as using performance standards for operating HVAC equipment in commercial structures, may provide additional measures to ensure adequate indoor air quality in both residential and commercial buildings.

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PROGRESS CHECK

1. **What are the differences between public health and occupational health standards and guidelines?**

2. **What are the primary public health standards or guidelines that are applied to indoor air quality problems? Briefly describe each.**

3. **What is a source emission standard? Give an example.**

4. **What are the some of the ventilation standards/guidelines that are applied to indoor air quality problems? Briefly describe each and identify the main provision of each.**

5. **Discuss the advantages and disadvantages of existing standards/guidelines for indoor air quality contaminant levels and ventilation.**

LESSON 8
INVESTIGATION TECHNIQUES

The investigator may be called upon to evaluate a variety of situations including complaints at residential, public, and commercial buildings. In other situations, the investigator may want to conduct a survey or study for research purposes. The specific investigation techniques may vary with each of these cases, but the underlying principles will be the same.

The complexity of indoor air quality investigations can range from those in which the sources, health effects, and solutions can be identified easily to complicated investigations which are difficult to resolve.

Before embarking on any investigation, the investigator should have a basic understanding of the types of factors that can influence indoor air quality (Lesson 2); health effects related to indoor air contaminants (Lessons 3 and 4); measurement methods (Lesson 6); and standards and guidelines for indoor air quality and ventilation (Lesson 7). The investigator will have to integrate this knowledge during the course of the investigation to solve a specific problem or to research a specific issue.

The focus of this lesson is the investigation of residential indoor air quality problems. Section 8 of the Reference Manual provides a detailed discussion of techniques for individual contaminants. Information on the investigation of nonresidential buildings can be obtained by contacting the Indoor Air Division of EPA (see Resources).

LESSON OBJECTIVES

At the end of this lesson you will be able to:

- **discuss the methods of gathering data;**
- **understand the general process for investigating indoor air quality problems;**
- **identify the systems to be evaluated in residential indoor air quality investigations; and**
- **discuss the principles for achieving effective communication with clients.**

INVESTIGATION PROTOCOLS *(RM 8)*

As yet, there are no widely accepted standard methods or protocols for indoor air quality investigations, particularly residential investigations. This should not be interpreted to mean that none should be used. In fact, it must be emphasized that a systematic approach is needed in both residential and nonresidential investigations. Several approaches have been developed for nonresidential investigations, (Woods *et al.*, 1989; Sterling *et al.*, 1987; NIOSH, 1987). and these can either be used directly or adapted for a particular purpose. Several professional associations are also developing or considering the development of protocols for indoor air quality investigations. For example, the American Society for Testing and Materials (ASTM) has established Subcommittee D22.05 on Indoor Air to develop standard methods and practices applicable to indoor air quality surveys and investigations. The Indoor Air Division of EPA can also be contacted for the latest EPA information and guidelines.

While standard protocols are limited, there are basic principles which are emerging as statements of good practice in investigating complaints, regardless of the type of building. The investigation of indoor air quality problems is similar to detective work; the investigator must search through the potential clues carefully to solve the case. Because of the inherent potential complexity of many indoor air quality problems, it has been recommended that a multidisciplinary team of individuals with expertise in the measurement of contaminants, building systems, and health effects should be employed to evaluate complex indoor air quality problems. This approach may be required, for example, in the investigation of high rise office buildings. However, the majority of indoor air quality complaints, especially in residences and smaller buildings, can often be handled by a knowledgeable person who understands the technical framework for solving indoor air quality problems. This lesson develops an investigation strategy for residences and smaller buildings. Some aspects of large office building investigations will differ from the approach outlined in this lesson and additional guidance can be obtained from the previously mentioned sources.

STANDARDIZED SURVEY FORMS *(RM 8)*

Several stages are involved in gathering information in an indoor air quality investigation (see below). In each of these stages, survey forms (questionnaires, activity logs, checklists) may be an important way of gathering information in a standard form. These forms (sometimes called instruments) can be developed for individual projects or "off-the-shelf" forms can be used.

Two basic types of forms are used for investigations:

- ***Questionnaires*** consist of a series of questions posed either by the investigator in person, over the telephone, or by mail to the subject about him/herself, other occupants, or the structure. The investigator can also complete a questionnaire about the structure without the input of the occupant during a walk-through of the structure (discussed below). Questionnaires can include open-ended questions or simple yes/no questions. Forms with yes/no type of responses are sometimes called checklists.

- ***Activity logs*** are diaries that are kept by the occupant on his/her activities during the course of a day, week, month, or longer. The activity log may require the occupant to note either in longhand or on a checklist when certain activities occur (for example, turning on a kerosene heater) and when symptoms occur.

In any investigation, procedures should be developed to ensure that the confidentiality of information contributed by clients is protected.

For most routine investigations of residential properties, a single instrument can be used to evaluate health complaints and the systems of the structure. An example questionnaire is provided in Section 8 of the *Reference Manual*.

When new forms are developed, extreme care must be taken to ensure that unbiased information will be collected. The survey form should meet two criteria: 1) the information to be collected must meet the objectives for doing the survey, and 2) the wording of questions, directions, and other communications must ensure that the information obtained will be accurate, complete, and consistent.

The design of questions is a separate field of study. Because there are many ways in which bias can enter a study or investigation, it is wise to consult with someone who has expertise in questionnaire design to make sure that a new questionnaire will result in the collection of accurate and unbiased data.

STAGES IN AN INVESTIGATION *(RM 8)*

Most investigations will probably be in response to residential complaints or requests before a house is occupied, during the time a house is occupied, or when a real estate transaction is contemplated. In the future, indoor air quality investigations may become an important component of residential real estate environmental audits.

An indoor air quality investigation is an iterative process involving discussions with the client, direct observations of the building, and, in some cases, measurements of environmental conditions. Throughout this process, the investigator develops and tests hypotheses and, through a process of elimination and narrowing, attempts to seek a solution.

Often, the client may be helped to a solution simply by following a number of suggestions made by the investigator based on knowledge of "good practice," without ever identifying a specific contaminant, source, or cause of the problem. Proper care and operation of appliances, provisions for adequate ventilation, and controlling microbiological contamination are examples of good practice that may solve some indoor air quality complaints.

Investigations are most efficiently conducted using a phased approach that opens with an initial contact, progresses to an investigation which may or may not include a characterization of contaminants, follows with an evaluation of results, and finishes with a report of results which may include recommendations for referrals. If recommendations or referrals are followed, the investigator evaluates the effectiveness of each and closes the case by reporting on the results (Figure 8-1).

At each of these stages the investigator plays an important role in educating the client about indoor air quality and general environmental health problems that come to the investigator's attention during the course of the investigation.

The Initial Contact

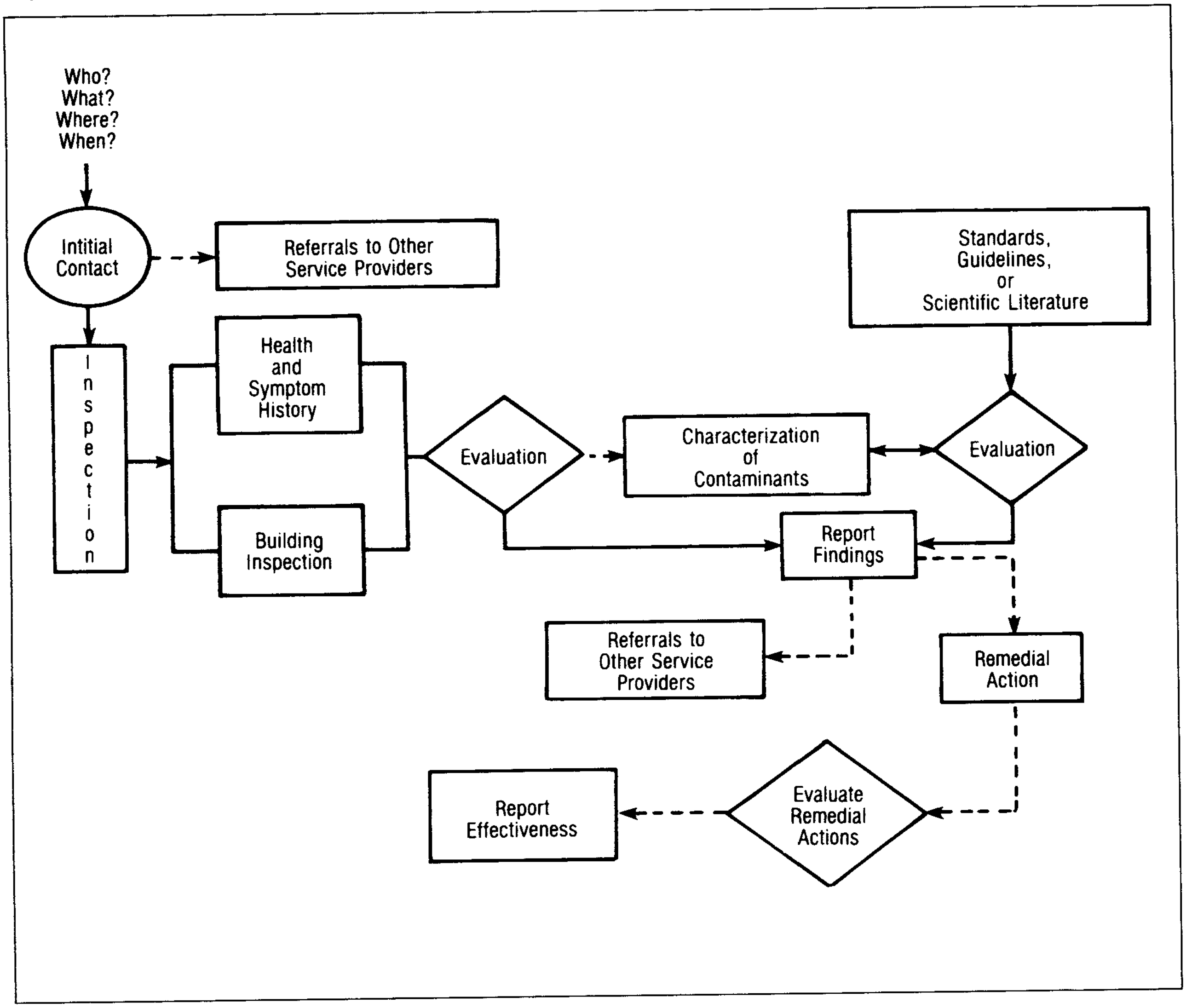
Investigations are usually initiated by a telephone call from an individual who has a concern or a problem. The initial contact is a time for information gathering, and the investigator begins to develop preliminary ideas about the problem. The initial interview should begin to answer the following questions:

- What is the problem?
- Where is the problem?
- Who is affected?
- When does the problem occur?

Much can be accomplished during the initial contact, and its importance should not be underestimated. At this stage, it is possible to:

- solve the problem;
- provide information or literature that may be useful to help the client understand

Figure 8-1. Flowchart of an investigation stategy for indoor air quality problems.



indoor air quality, take actions to improve indoor air quality, or find a solution to identified problems;

- suggest initial actions that will test preliminary hypotheses to help narrow the possible causes;
- schedule an appointment for a site visit; or
- refer the client to other service providers.

Although standardized forms do not need to be used at this point, it is important to use a *systematic* approach when obtaining preliminary information. Try to get information that is specific. For example, if there is a health complaint, a general statement, "I haven't felt well in weeks," does not give much insight. However, complaints of headache which are limited to times when unvented combustion sources are present, or upper respiratory tract irritation which started when a room was remodelled, give more clues about possible causes. Sometimes, however, complaints will not be specific and clients will not be able to relate complaints to specific events.

Because there are many factors which can influence the response to contaminants, it is important to remember that there can be a wide range of responses from individual to individual and within a single individual. This means that it is possible during an indoor air quality investigation to encounter only one person in a household or a few people in an office setting who complain of health symptoms. Their symptoms may be real and legitimate even though no one else is experiencing them, and the investigator has the responsibility of maintaining an open mind and following all leads that may be able to explain the complaints.

The time when the symptoms began is important. If the symptoms started three months ago, try to ascertain what major actions took place just prior to the onset--new home, new furniture, new furnace, change of season, new pet, and other changes. Questions can also help the client associate the symptoms with given activities or events. Questions of this nature may give clues about the potential cause, around which preliminary hypotheses can be formulated and verified by the client. The client may then be able to solve the problem, or at least call back at a later date with more information after taking some actions to test preliminary hypotheses.

For example, if the symptoms occur only after the client has gone to bed, the client might try sleeping in another room. If the symptoms go away, the source of the problem is probably in the bedroom. Or, the client might try removing potential sources or increase ventilation (for example, sleeping with the window cracked open) to see if the problems persist. If it is not clear that the cause of the symptoms is the air in the home, it may be possible for the client to spend several days away from home (for example, staying with a neighbor or relative) to see if the problems persist. If they do, the cause of the symptoms may be unrelated to the air in the home.

The Inspection

The best approach for conducting an inspection is to use standard forms (questionnaires, checklists, diaries) in all phases of the inspection. This reduces problems with information recall, lost notes, deciphering cryptic messages, and bias. Another reason for using standard forms is that the investigator's records may become part of a legal action.

Health Effects Evaluation

The inspection should begin with the administration of a health effects questionnaire which can be completed either by the client or administered to the client by the investigator. A health effects questionnaire should be broad enough so that other confounding health problems will be elucidated.

When an occupant perceives an indoor air quality problem, it is usually in response to a health or discomfort symptom or an odor. Because of the overlap of symptoms and the sometimes general nature of symptoms ("I just don't feel right."), health and comfort complaints must be interpreted carefully. The health effects questionnaire will be a useful tool in guiding the investigation, but it should never be the sole focus. If the investigator becomes fixed on symptoms, it is possible that other important indoor air-related factors may be obscured or overlooked.

Health effects forms can range from a simple checklist to more sophisticated questionnaires that employ a combination of checklists, open-ended questions, and yes or no questions.

A useful approach in obtaining information about health symptoms is to utilize a checklist of symptoms that begins to identify both the severity and frequency of symptoms (Section 8 of the Reference Manual). It is also important to obtain histories of smoking, caffeine intake, medical problems and use of medicines, occupation, hobbies, and craft activities. Health care providers such as family physicians, nurses, allergists, and pulmonary specialists should be consulted as needed (always with permission from the client). All of this information may be useful in narrowing the scope of the investigation and identifying potential indoor air quality causes of symptoms.

Building Evaluation: Walk-Through

After the health history is obtained, the investigator may then proceed to evaluate the structure and its environs (Section 8 of the Reference Manual). The client should be invited to accompany the investigator on the walk-through. A standard form should be employed to evaluate the different systems of the house or building both for sources of contaminants and condition. Rooms should be evaluated to determine if they are being used as intended. The walk-through should also include an evaluation of the exterior of the structure and the site. Finally, the evaluation should identify the use of chemicals in the building and any new events or activities which might affect indoor air quality or health.

When conducting the walk-through, the investigator should keep an open mind. If the investigator focuses on finding sources of a particular contaminant, other problems can be overlooked. The walk-through of the home should systematically evaluate the following areas.

- ***The Site***
  air pollution, geology and soil, water supply (especially private sources), surrounding obstacles, noise, electromagnetic fields, accumulated bird droppings, other potential sources of contamination

- ***Building Materials***
  roofing materials, exterior finishes, interior surface materials, interior surface finishes, insulating materials, signs of moisture accumulation or damage, presence of asbestos-containing building materials

- ***Heating, Ventilating, and Air-Conditioning Systems***
  combustion and noncombustion sources, venting of combustion sources, backdrafting of flue gases, venting of kitchen and bathroom, ducting materials, humidifiers, energy conservation measures, temperature, humidity, airflow and balance, microbial contamination, presence of asbestos insulation

- ***The Foundation***
  drainage and condition, recent treatment or pesticide applications

- ***The Basement***
  dampness and condition, recent termiticide treatment or other pesticide applications, radon, other soil gases

- ***The Crawl Space***
  drainage, ventilation, condition, and recent termiticide treatments or other pesticide applications

- ***Client Activities***
  use of chemicals and consumer products which may produce air contaminants

- ***Building Interiors***
  changes in building or room use; changes in interior design; recent decorating changes or renovation; evidence of mold; condition of appliances; presence of unvented combustion appliances

- ***Attached Garage***
  potential flow of contaminants into the living space

During the walk-through, the investigator should mentally review the reported health effects, potential sources of contaminants, and the condition of different systems in the building. This helps the investigator to develop a picture of the total environment and how that environment could contribute to indoor air quality problems.

Special attention should be given to indicators of inadequate ventilation in residential and nonresidential investigations. The investigator should always consider evaluating humidity, temperature, and airflow in the home to complete the basic profile. In addition, the adequacy of outdoor air (and perhaps carbon dioxide as an indicator of the adequacy of ventilation) should be considered in the evaluation of nonresidential buildings. After this preliminary information has been obtained, the investigator can decide whether or not to sample for the presence of indoor air contaminants. **In many investigations, the walk-through and health effects screening are enough to identify the problem, and the measurement of contaminants is not needed.**

Characterizing Contaminants

If the investigator decides that a characterization of contaminants is needed, sampling can be conducted on-site if the equipment is available. If not, a follow-up appointment is required. It is best to evaluate carefully the results of the health screening and the inspection before making a decision to monitor in order to maximize resources and minimize disruption by repeat visits. Testing should be selective and include only those contaminants or agents suspected of causing problems. An exception to this selective approach is sampling for radon (recommended by EPA for all residences) and identifying potential asbestos-containing materials.

Monitoring for contaminants and physical parameters should be conducted in a systematic fashion to characterize both worst-case and average exposures. Knowledge of both of these exposures is needed to evaluate the potential risk to those who are exposed. Average exposures refer to conditions that usually exist in the household. In order to obtain worst-case exposures, conditions may require modification. Short-term sampling (for example, for radon, formaldehyde) requires that the house be closed as much as possible for 12 hours before sampling and during sampling.

Contaminants should be sampled where and when symptoms are experienced, where the individual spends the most time, and where suspect sources are located. The investigator must sample for a sufficient time to collect samples that will yield meaningful data.

Proper placement of samplers is critical. Samplers should be located at breathing height. They must be located away from dead air spaces; locations next to windows and doors may bias results due to high infiltration/exfiltration. Samplers should be located sufficiently away from objects such as curtains and partitions that affect air flow.

In some situations, it may be appropriate to test materials (for example, potable water from private wells for radon or VOCs, and insulation for asbestos).

Evaluation and Reporting of Results

The evaluation of the health, inspection, and monitoring data is perhaps the most difficult aspect of the investigation for several reasons.

- There is considerable variability in human response to contaminants, and many of the symptoms resulting from exposure to indoor air contaminants are similar to those of other health problems and stress.
- There is a lack of standards and guidelines, and even when standards or guidelines exist, they cannot be used in a cut-and-dried manner because of the variability in response.
- The symptoms experienced may be from exposure to multiple contaminants at relatively low levels of exposure. Analysis of individual contaminants in these circumstances will not yield meaningful results.

When monitoring is conducted, these data must be integrated into the results of the health screening and inspection to identify sources of problems and recommend solutions. In some instances the investigator may have to consult the scientific literature to evaluate reported symptoms and measurements.

If in the investigator's judgment, monitoring is not needed, but an indoor air quality problem exists, remedial actions may be recommended either for the original complaint or for subsequent problems which are revealed during the inspection.

Finally, after all of the information has been collected, digested, and evaluated, the client should be informed of the results of the investigation. Results may be given initially by telephone, but a written report or letter which summarizes the investigation and its results should always be sent. A written report that is complete and understandable (without bureaucratic and technical jargon) will save the investigator's time, and it provides the client with a permanent record that should not be subject to conjecture. Copies may also be sent to interested parties such as physicians (upon the request or approval of the client).

Referrals to Other Service Providers

There will be instances when, in spite of the investigator's efforts, no apparent cause of reported symptoms can be found. This situation can be frustrating to both the investigator and the client, but it should be handled in a direct manner with the client. If there are other potential avenues of exploration that the investigator was unable to follow, these should be communicated to the client. The investigator may also recommend that the client contact other agencies or medical personnel to pursue health and environmental complaints which are beyond the jurisdiction of the investigator. Clients should always be advised to consult with their health care provider.

If referrals to private laboratories, consultants, and remediation services are needed, the investigator should furnish the client with a list of potential vendors. The investigator should not be placed in the position of recommending a single individual or company.

COMMUNICATIONS *(RM 8)*

One of the most important, but often overlooked, components of a successful indoor air quality program is the way in which complaints, inspections, and requests for information are handled. Communication with the client is an integral part of all aspects of the investigation of an indoor air quality problem beginning with the initial contact and ending with the communication of results. Effective communication is the key to success, and it requires skill and practice to achieve.

The investigator should share information with the client as the investigation progresses; this will make the process less mysterious, alleviate anxiety, and ensure that effective communication takes place. During all phases of the investigation, the attitude of the investigator and the ability of the investigator to communicate with the client will influence the overall success of the investigation. Guidelines that have been developed for successful complaint investigation also apply to indoor air quality investigations. These include: listening, caring, informing, taking action, documenting, and following-through (Herman, 1983).

Communications During the Initial Contact

Initial contacts are usually made by telephone, and this opportunity should be used to explain capabilities and gather as much information as possible to assist with developing an overall strategy for problem-solving.

Keeping an open mind is a cardinal rule. Situations should not be prejudged based on reactions to a client. When a homeowner or other person complains about an indoor air quality problem, he may share his own frustration about dealing with the bureaucracy, physicians, or private industry. The individual may be anxious or angry. Typical questions include: "Have you ever heard of this before?" "Why is this chemical/product allowed to be used?" "Can you make someone do something about this?" "Should anyone have to live/work like this?"

It is important to demonstrate a healthy concern about the problem that is being presented. Listen carefully, take notes, ask questions or get clarifications, and be professional and polite during all contacts. Keep the discussion focused on the issue in an organized manner to yield information for diagnosing and solving the problem. Occasionally, individuals who are very anxious or seem unduly panicked will call. These calls should receive the same consideration as any other call to determine if the symptoms reported are associated with the quality of the indoor air. Under no circumstances should a caller ever be handled in a cavalier or demeaning manner.

In extreme cases, referral to appropriate legal or social service agencies may be needed. Permission of the client may be required in some jurisdictions for referral to a physician or other health care provider.

When asking questions, use a systematic approach, and repeat information back to the client so potential errors will be minimized. It is important to allow the individual to explain the problem and symptoms, and to refrain from leading; the investigator should always be aware of the potential to lead.

After collecting preliminary information, some ideas about possible avenues for further investigation may emerge. This is the time to explain your capabilities to the caller. Does the department handle these types of complaints? If so, when can an investigation be scheduled? Will there be a fee for any of the services that could be provided? Explain the procedure for investigating a complaint; explain your goals in investigating the complaint. If the person wishes you to follow up, schedule an appointment.

In order to maintain a good working relationship, be on time for scheduled inspections. It is always a good idea to confirm an appointment by telephone.

If the investigator has any important observations after obtaining the health and symptom history, these should be shared with the client before proceeding with the investigation. For example, if the individual is concerned about radon, but is complaining about watery eyes, it is appropriate to let him know that watery eyes are not related to radon exposure, but there may be other possible explanations.

Communications During the Investigation

During the investigation, potential sources that will be of particular interest can be identified to the client; if nothing appears to stand out, that can also be shared. Remember, it is anxiety-producing not to have information. Sharing information is also likely to result in more information and cooperation from the client.

In some instances, the investigator may need to speak to a client's physician to get a more detailed history for a specific complaint. Although it is possible for a client to call health care providers and give them permission to talk to the investigator, this is not a good practice. The client should be asked to send the physician or other provider a release request that specifies the information that can be released.

If contact with a physician or other health care provider is necessary, be sure to explain your role, obtain the needed information, identify any hypotheses that you have, and get feedback from the health care provider on your hypotheses and the reported health complaints. The health care provider may want to conduct medical tests on the client which may be helpful, or these data may have already been obtained. This may also be a good opportunity to share information that will inform the health care provider about indoor air quality problems with which he/she is not familiar.

If monitoring is needed, explain to the client what tests are needed and what the results may or may not reveal. If preliminary and conclusive results are available at the site, share them with the client, explaining how the data relate to standards or guidelines. Any limitations of the data should be communicated clearly. Indicate that the information is preliminary and that a final report will follow.

Time spent during the inspection to keep the client informed will help the client become knowledgeable and less apprehensive about indoor air quality problems.

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PROGRESS CHECK

1. **What are the two basic types of survey forms, and what criteria should any survey form meet?**
2. **What basic elements are involved in conducting a residential investigation?**
3. **What are the systems that should be evaluated during an inspection?**
4. **Explain an effective approach to characterizing contaminants.**
5. **What are the basic elements of effective communication?**

LESSON 9

ESTABLISHING AN INDOOR AIR QUALITY PROGRAM

The responsibility for developing new environmental health services often rests with environmental professionals who are not involved in day-to-day program administration. This unit is provided for the reader who either may want to propose an indoor air quality program within an organization or may actually be given the responsibility for implementing a program without having had previous administrative experience. In either case, understanding the basic elements of program management will be critical to one's success in nurturing a new program.

LESSON OBJECTIVES

At the end of this lesson you will be able to:

- **identify the basic elements of program management;**
- **know how to develop program objectives;**
- **identify the principal components of a program budget; and**
- **understand the concept of program evaluation.**

Defining Program Need

The need for any new service must be carefully justified, especially one that is still relatively unfamiliar to most people. In the case of indoor air pollution, one must be prepared to educate decision-makers and others likely to influence the allocation of resources about the types of indoor air hazards and associated health risks. As much as possible, these risks should be discussed within the context of the population served by the organization.

It will be necessary to make a persuasive case that there are potential indoor air problems, and the needs of the community are not being met. Documenting actual indoor air problems within the geographical area of concern without having an active indoor air program may be difficult. However, there are now numerous research studies and articles in the popular press and trade journals which provide a basis for assessing the potential magnitude of indoor air contaminants on the population within a given area. Some types of information which can be used to support the need for indoor air quality services include:

- Records of requests for service from citizens who believe they are being exposed to indoor air hazards.
- An aging housing stock can be a source of carbon monoxide caused by faulty furnaces, or these structures can contain friable asbestos.
- The indoor air problems encountered in both new and old commercial office buildings are well-documented and are common to most geographical areas.
- The U.S. EPA and the Surgeon General have recommended testing all residences for radon.
- A large number of manufactured housing units in the community could be an important source of formaldehyde exposure.

Program proposals seldom succeed on their merits alone. It is important to adhere to the organization's chain-of-command when proposing a new program, and one must be alert to the politics of the organization. As the proposal progresses one should be prepared to provide clarifying information to key decision-makers, such as board members, elected officials, and interest groups whose support will be important both before and after the program is implemented.

One should be prepared to respond to questions about the most common indoor air quality problems, resource needs, federal and state activities, what the program will do, and how it will be done.

Elements of a Program

Basic elements of a program which could be considered include:

1) mechanisms to respond to complaints;

2) providing public information and guidance;

3) analytic studies to define the nature and magnitude of the problem in the jurisdiction;

4) conducting residential and commercial building investigations;

5) special programs to deal with individual hazards such as radon, asbestos, and pesticides;

6) distribution of federal and state guidance to the building community and the public;

7) publishing directories of contacts within the jurisdiction for individual subject areas relevant to indoor air;

8) coordinating activities with other agencies at the local, state, and federal levels; and

9) developing an appropriate legal framework and enforcement capability.

Program Resources

During the initial planning stages one seldom knows exactly how much money is likely to be committed to a new program. Preparing several options with cost estimates may be desirable for at least two reasons.

- First, it starts to bring the major program priorities into focus and provides the program manager with an outline of an action plan once the funding level is determined.

- Second, the people who decide upon the funding level can more easily reach a decision if they can review a limited number of options spelled out in reasonable detail.

As a practical matter, everyone in the decision-making process will feel more confident about the proposal if they believe the person who initiated it has both a command of the details and an open-minded view of the alternatives. Each program alternative should include cost estimates. Potential costs include:

- Personnel Costs--wages, salaries, and benefits for full-time and part-time personnel; benefits include social security, retirement, medical insurance, life insurance, and other programs offered to employees by the organization;

- Equipment--items for conducting indoor air investigations, office equipment, computer hardware, and furniture;

- Supplies--items such as paper, pens, pencils, postage, batteries, and computer supplies;

- Building rental or purchase costs;

- Utility payments;

- Training programs;

- Consultant fees;

- Maintenance Costs--includes field testing equipment and major office equipment;

- Vehicle costs or mileage payments for field personnel;

- Computer software;

- Computer access time; and

- Laboratory fees.

The preceding list is not intended to be comprehensive, but it should provide a general guide to overall program costs. Specific cost information for items not unique to an indoor air program usually can be obtained from purchasing or accounting specialists within the organization. Information about wage and salary classifications as well as benefits, should be available from line managers within the chain-of-command or from personnel specialists.

For information about special equipment needs and costs, other public agencies involved in indoor air investigations can be helpful. Equipment vendors are very accommodating about providing specifications and pricing information. Professional environmental health associations and academicians are other valuable resources within the information network.

The costs of the indoor air program should be projected beyond the "start-up" period. Additional overhead costs will be incurred by the organization if a new program and additional staff are added; support functions such as personnel, payroll, and accounting will have to absorb an additional workload.

The indoor air program may be able to generate revenue to offset costs. Charging fees for services has become increasingly popular in the public sector as traditional revenue sources have been stretched to the limit. This is an issue worth exploring, but be aware that the politics can be more complex than the economics, and acquiring an understanding of the prevailing policies toward service fees within the political subdivision is important.

Personnel

Initial staffing requirements will depend upon both the nature of the program's objectives and the funding commitment. Most state and local indoor air programs have modest beginnings, with one or two full or part-time environmental health specialists. Job descriptions, candidate qualifications, and position salary classifications should be determined in conjunction with personnel specialists; however, the program manager will be relied upon to help define the educational and experience background needed by the indoor air specialist.

An entry-level indoor air specialist usually has an academic background in environmental health, industrial hygiene, or other closely related area. Candidates should also have a working knowledge of environmental chemistry, toxicology, air sampling techniques and instrumentation, and a knowledge of ventilation systems. It may be possible to correct deficiencies in these and other areas through formal training programs, self-instruction courses, or on-the-job experience.

Training programs in indoor air quality and various sub-specialties are available from many sources. Agencies of the Federal government provide periodic training programs on a variety of topics at regional centers. Many universities now offer short-term educational programs, and faculty members may individually assist state and local government personnel with technical issues. Professional associations such as NEHA, ASHRAE, ACGIH, Air and Waste Management Association, American Society for Testing and Materials, Health Physics Society, and others conduct educational conferences and meetings, often specifically related to indoor air quality topics. These opportunities for "networking" with other indoor air professionals can be extremely valuable.

Program Implementation

Once the resources are secured, a program manager will be designated to implement the indoor air program. It is the program manager's responsibility to make the most effective and efficient use of available resources. Very simply, the manager must have a plan, and planning involves specifying program objectives.

An objective is basically a statement of a result which one intends to achieve. Ideally, the statement should say what the result will be and when it will be accomplished. It should also be clear who is expected to achieve the objective. Of course, all objectives which are set should relate to the overall goal(s) established for the indoor air program. A broad goal might be to reduce risks to human health related to indoor air hazards. This serves to remind everyone why they are there, and that everything they do should help move the program toward that goal.

More specific objectives should focus on major priorities. Initially, the objective might be to establish a fully operational indoor air program by a particular date. Objectives must be realistic, measurable, and attainable. The success of an objective can be increased by devising action plans, which are simply stepping stones toward the desired result. All of these plans need the full involvement and commitment of those who will have responsibility for implementing them.

While major program objectives are contingent upon area needs, as well as organizational priorities and resources, the following are a few examples of objectives pursued by existing indoor air programs:

a) conduct a radon exposure study in randomly selected residences to be completed by (date);

b) correct hazards (specify percent) identified during building complaint investigations;

c) identify and correct all friable asbestos conditions within municipally-owned buildings by (date); or

d) conduct a survey to determine if unvented space heaters are being used in a manner which is creating indoor air contamination problems.

There are other policy and procedural issues that will need to be addressed, and a few of these may have a bearing on the general direction of the indoor air program. One major question is whether the program will be purely consultative and educational, or whether enforcement will be a component of the program. If there is to be enforcement, a legal structure will have to be in place, including ordinances or statutes, an administrative appeal process, a willing prosecutor, and legal staff.

Community awareness of the indoor air issues and program services is another consideration in planning health education objectives, and it can also affect staff workload. Publicity about the program will generally result in more requests for service, which affects both field investigation and clerical staffs. Program management, as much as possible, should influence the nature and timing of public information so that it will have maximum educational benefit, minimize public confusion and overreaction, and not tax program resources with the demand for services that will likely result from the release of information.

Program Evaluation

The process of evaluating a new program starts during the implementation phase and culminates with an assessment of what was actually accomplished compared to the expectations defined by the major objectives. The only way to evaluate a program at any stage is to have an adequate amount of information that reflects what is happening and what is being achieved. A thorough record-keeping system must be developed which indicates how program personnel spent their time and what they accomplished. As with all environmental health programs, inspections and other field activities will have to be thoroughly documented. The organization will also have to document the expenditure of funds for all of the items specified in the budget.

A primary function of the program manager is to review summary data derived from records kept by field and support staff. Time must also be spent communicating with all staff members, whether in informal discussions or in a more structured setting such as a staff conference, in order to understand staff concerns and to benefit from ideas about program improvement.

The point of program evaluation is to determine whether the program is effective and efficient. Determining program efficiency involves comparing the level of input to the level of output, or relating costs to the amount of services produced. Over time, efficiency information can help determine what level of services can be provided for a given amount of money, and it can also help the program manager diagnose operational problems. However, drawing meaningful, precise, cost efficiency information can be a complex task because the cost of each activity in the indoor air program will have to be calculated. The program manager will either have to become familiar with cost accounting procedures, or seek the assistance of someone who is knowledgeable. Most initial program evaluation efforts, however, will probably focus on determining program effectiveness rather than efficiency. Effectiveness in the public sector is a measure of a program's success in fulfilling important public needs. The major objectives of the indoor air program should reflect the community's needs and the program manager must be able to determine the program's level of achievement. If any objectives were not met, the manager must identify the reasons based on available information. It may be that the resources were inadequate or personnel did not perform up to expectations. Similarly, other obstacles may have arisen which were not identified at the outset.

The process of program evaluation is a time for reassessment and a preparation for future objective-setting. Although objectives should be taken seriously, they are not carved in stone and should be modified whenever it is clear that one's initial assumptions were not valid. Similarly, if the objectives were valid but unmet, it is necessary to find and correct deficiencies in the operation. Finally, the manager must clearly communicate to key decision-makers the successes, and thus the effectiveness, of the indoor air program in order to ensure future support.

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Ruchelman, L.I. 1985. *A workbook in program design.* State University of New York Press: Albany, NY.

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PROGRESS CHECK

1. **What types of information are needed to justify the need for an indoor air program?**
2. **Name six major budget items that should be included in a program proposal and indicate where you would obtain the cost information.**
3. **What are some possible elements of a program objective?**
4. **What possible effects should a program manager take into account before deciding to publicize the indoor air program?**
5. **What are possible reasons for the lack of effectiveness of an indoor air program?**

RESOURCES

National Hotlines and Information Services

Public Information Center (PM 211 B)
Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460
202-382-2080
(Distributes IAQ Publications)

National Pesticides
Telecommunications Network
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)

Safe Drinking Water Hotline
202-382-5533

CPSC Product Safety Hotline
1-800-638-CPSC
Teletypewriter for the hearing impaired
Outside Maryland 1-800-638-8270
Maryland only 1-800-492-8104

Federal Agencies

Indoor Air Division (ANR-445W)
Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460

Office of Conservation and Renewable Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washingon, D.C. 20585

Office of Smoking and Health
U.S. Public Health Service
5600 Fishers Lane Room 1-10
Rockville, MD 20857

Consumer Product Safety Commission
Chemical Hazards Program
5401 Westbard Avenue, Rm. 419
Bethesda, MD 20207

National Institute for Occupational Safety and Health
Hazards Evaluations and Technical Assistance Branch (R-9)
4676 Columbia Parkway
Cincinnati, OH 45226

Occupational Health and Health Administration
U.S. Department of Labor
200 Constitution Avenue, N.W.
Washington, D.C. 20210

Bonneville Power Administration
Residential Programs Branch
P.O. Box 3621-RMR
Protland, OR 97208

Tennessee Valley Authority
Industrial Hygiene Branch
328 Multipurpose Building
Muscle Shoals, AL 35660

Health/Consumer Organizations

Your Local Lung Association, or the
American Lung Association
1740 Broadway
New York, NY 10009

Consumer Federation of America
1424 16th Street NW, Suite 604
Washington, D.C. 20036

Professional/Industrial Associations

American Society of Heating, Refrigerating, and Air-Conditioning Engineers
1791 Tullie Circle NE
Atlanta, GA 30329

American Conference of Governmental Industrial Hygienists
6500 Glenway Avenue
Building D-7
Cinncinati, OH 45211

American Industrial Hygiene Association
P.O. Box 8390
345 White Pond Drive
Akron, OH 44320

American Society of Testing Materials
Subcommittee D22.05 Indoor Air Quality
1916 Race Street
Philadelphia, PA 19103

Canada Mortgage and Housing Corporation
National Office
682 Montreal Road
Ottowa, Ontario Canada KIAOP7

National Air Duct Cleaners Association
1518 K Street NW
Washington, D.C. 20005

National Association of Home Builders
15th and M Street, NW
Washington, D.C. 20005

National Center for Appropriate Technology
P.O. Box 3838
Butte, MT 59702

National Environmental Health Association
720 South Colorado Blvd.
South Tower Suite 970
Denver, CO 80222

National Pest Control Association
8100 Oak Street
Dunn Loring, VA 20027

Home Ventilating Institute
39 West University Drive
Arlington Heights, IL 60004

EPA REGIONAL OFFICES

(Write to the Indoor Air Contact at the appropriate office below)

EPA Region 1
JFK Federal Buildig
Boston, MA 02203
(CT, MA, ME, NH, RI, VT)

EPA Region 2
26 Federal Plaza
New York, NY 10278
(NJ, NY, PR, VI)

EPA Region 3
841 Chestnut Street
Philadelphia, PA 19107
(DE, MD, PA, VA, DC)

EPA Region 4
345 Courtland Street, NE
Atlanta, GA 30365
(AL, FL, GA, KY, MS, NC, SC, TN)

EPA Region 5
230 South Dearborn Street
Chicago, IL 60604
(IL, IN, MN, OH, WI)

EPA Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
(AR, LA, NM, OK, TX)

EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(IA, KS, MO, NE)

EPA Region 8
One Denver Place
999 18th Street, Suite 1300
Denver, CO 80202-2413
(CO, MT, ND, SD, UT, WY)

EPA Region 9
215 Fremont Street
San Francisco, CA 94105
(AZ, CA, HI, NV, AS, GU, TT)

Region 10
1200 Sixth Avenue
Seattle, WA 98101
(AK, ID, OR, WA)

FINAL EXAMINATION INSTRUCTIONS

The final examination consists of 86 multiple choice questions on the content of the entire module. It is a learning tool as well as a measure of your understanding of the material.

Use Answer Sheet

Mark your answers on the answer sheet provided, being sure to follow the directions given. Make certain that you complete all the information requested on the answer sheet.

Read Carefully

Read each question carefully. There is only one correct answer to each question. NEHA will score your exam and return your corrected answer sheet.

Minimum Score

Since this is an "open-book" exam, a minimum score of 75 percent correct must be achieved. You will receive a certificate of completion if you score this minimum or higher.

Time for Completion of the Module and Final Examination

Please indicate in the space provided the amount of time you spent in studying the material and completing the final examination. This information will assist NEHA in determining the number of continuing education credits that will be granted for this course.

MAIL YOUR ANSWER SHEET TO:

National Environmental Health Association
720 South Colorado Blvd.
#970 S. Tower
Denver, CO 80222

FINAL EXAMINATION

1. **Which of the following are reasons for concern about indoor air today?**
   a. people spend most of their time indoors
   b. the use of natural ventilation has decreased
   c. many buildings and furnishings are produced from synthetic chemicals
   d. all of the above are reasons for concern

2. **Which of the following statements is correct?**
   a. the relationship between indoor air pollution and health has been intensively studied for about 30 years
   b. staying indoors always protects inhabitants from outdoor air pollution
   c. the reduced air changes in new construction is one reason for the deterioration of indoor air quality
   d. people are probably exposed to fewer indoor air contaminants today than 50 years ago

3. **Which of the following can affect the quality of indoor air?**
   a. vegetation surrounding the house
   b. quality of water supply
   c. geology
   d. all of the above can affect indoor air quality

4. **Which is most likely to be a potential source of formaldehyde?**
   a. particleboard subflooring
   b. roofing felt
   c. paint
   d. solid hardwood floors

5. **Volatile organic compounds are most likely to be released from which of the following sources?**
   a. asbestos insulation
   b. freshly painted interior room
   c. recently poured concrete basement floor
   d. old, moldy carpet

6. **Which contaminant is more likely to result from an outdoor source than an indoor source?**
   a. asbestos
   b. radon
   c. volatile organic compounds
   d. pollen

7. **Which statement about air exchange rate is correct?**
   a. air exchange rates of older houses that have not been weatherproofed are typically in the range of 0.10 ach to 0.5 ach
   b. air exchange generally increases with strong winds
   c. air exchange can be increased through the use of vapor barriers
   d. indoor air contaminant concentrations will always be inversely proportional to the air exchange rate

8. **Assuming all other factors are constant, which conditions will result in the highest infiltration rate?**
   a. outside temperature of 32°F, inside temperature of 68°F
   b. outside temperature of 70°F, inside temperature of 75°F
   c. outside wind calm
   d. cloud cover and rain

9. **If a house has a volume of 15,000 ft^3 and air is replaced at a rate of 500 ft^3 per minute, how many air changes are occurring each hour?**
   a. .5 ach
   b. 1 ach
   c. 2 ach
   d. .25 ach

10. **Which of the following statements is correct about providing natural ventilation through windows?**

    a. windows should be placed at the same level and near the ceiling for the most effective ventilation
    b. inlet and outlet openings of unequal size provide the greatest flow per unit area of total opening
    c. windows should be located opposite one another to increase ventilation flow
    d. a bank of windows should be oriented on the leeward side of a building to provide the greatest inflow of air

11. **Which of the following statements about health studies is correct?**

    a. animal studies can be conducted using invasive techniques that would not be allowed in human studies, and they provide data at exposures that are typical of indoor air concentrations
    b. epidemiologic studies can evaluate the effects of contaminants as people conduct their day-to-day activities, but it can be difficult to separate the effects of some factors
    c. human exposure studies can be conducted on healthy and ill subjects, and experimental conditions can be strictly controlled
    d. risk assessments are based solely on epidemiologic studies because of the limitations associated with animal and human exposure studies

12. **Which term correctly identifies the occurrence of eye, nose, and throat irritation in a person who walks into a new home?**

    a. acute effect
    b. chronic effect
    c. subtle effect
    d. delayed effect

13. **Which of the following is *not* a factor that determines whether or not health effects will result from exposure to indoor contaminants?**

    a. physical properties of the contaminant
    b. age and body size
    c. humidity level
    d. education level

14. **Which of the following are important properties of gases or particulates that determine whether they will affect the pulmonary region of the lung?**

    a. particle size and shape
    b. solubility
    c. chemical characteristics
    d. all of the above are correct

15. **Which of the following statements about dose is correct?**

    a. as the dose increases, effects usually reach a plateau and then decrease
    b. a person at rest receives a greater dose than one who is active because the air is in contact with the lungs for a greater length of time
    c. the dose received through skin absorption is greater than through inhalation because chemicals are directly absorbed into the body
    d. two people who are exposed to the same concentration of chemicals may or may not receive the same dose

Examination continues on next page

16. **Which of the following statements about the dose-effect curve is correct?**
    a. the linear dose-effect curve indicates that there is a dose below which effects do not occur
    b. the threshold dose-effect curve indicates that effects occur at all doses, no matter how low the dose
    c. carcinogens are generally considered to follow the threshold dose-effect curve
    d. none of the above are correct

17. **Which of the following is an example of a subgroup of the population which is probably more susceptible to health effects from chemical exposure than the general population?**
    a. infants and children
    b. pregnant women
    c. the elderly
    d. all are examples of subgroups that are probably at greater risk to health effects from chemical exposures

18. **Which of the following is an example of an irritant?**
    a. formaldehyde
    b. carbon dioxide
    c. carbon monoxide
    d. radon

19. **Which of the following is an example of a contaminant that could act as an irritant and also affect the central nervous system?**
    a. lead
    b. chlordane
    c. sulfur dioxide
    d. nitric oxide

20. **Which of the following is a condition in which the air sacs lose elasticity and breathing becomes more difficult?**
    a. bronchitis
    b. pneumonitis
    c. emphysema
    d. edema

21. **Hepatotoxicants affect which of the following body systems?**
    a. kidney
    b. blood
    c. reproductive organs
    d. liver

22. **Which of the following has been associated with a lack of natural light during the winter?**
    a. winter depression
    b. irritation of the eyes, nose, and throat
    c. cancer
    d. poor vision

23. **Which of the following is most likely to be associated with dry air?**
    a. fatigue
    b. chest pain
    c. irritation of the eyes, nose, and throat
    d. sweating

24. **Which of the following is a condition that has been associated with airborne pathogens or allergens?**
    a. migraine headache
    b. emphysema
    c. bronchitis
    d. humidifier fever

25. Which of the following is an asphyxiant that is released by combustion sources?

a. nitrogen dioxide
b. carbon monoxide
c. sulfur dioxide
d. respirable particles

26. Which of the following is a potential carcinogen which can be emitted from water, some building materials, and the soil?

a. lead
b. trichloromethane
c. PCBs
d. radon gas

27. Which of the following could be present in painted surfaces in older structures and could result in mental retardation?

a. benzene
b. cadmium
c. lead
d. styrene

28. Which of the following provides a real-time record of contaminant concentrations?

a. grab sampler
b. integrated sampler
c. continuous sampler
d. passive sampler

29. Which of the following statements about passive samplers is correct?

a. passive samplers utilize pumps to move air
b. passive samplers are difficult to use
c. passive samplers have limited accuracy
d. passive samplers can only be used to sample particles

30. Which of the following statements about active samplers is correct?

a. active samplers are limited to a narrow range of flow requirements
b. an active sampler that is widely used in indoor investigations is the personal sampling pump
c. active samplers are less accurate than passive samplers
d. active samplers require less training than passive samplers

31. Which of the following describes the collection of gases using a process in which the gas is attracted *to*, concentrated *in*, and retained *on* a substrate?

a. electrostatic collection
b. adsorption
c. impaction collection
d. absorption

32. Which of the following describes a method of collecting gases in which they are transferred *to* and dissolved *in* a liquid or solid?

a. absorption
b. inertial collection
c. adsorption
d. centrifugal collection

33. Which of the following statements about colorimetric indicator tubes is true?

a. they accurately measure contaminants
b. they do not require special handling
c. they can be used to sample both gases and particles
d. they are generally not recommended for indoor air quality investigations

Examination continues on next page

34. Which of the following statements about direct reading measurement methods is correct?

a. they provide concentration readings at the time a sample is collected without further analysis
b. they require low capital expenditures
c. they require laboratory analysis after collection
d. they do not require calibration

35. Which of the following statements about errors in the measurement process is correct?

a. systematic errors vary both in direction and magnitude and can never be completely eliminated
b. interferences will introduce random error into the measurement
c. routine calibration will reduce systematic error
d. nonrepresentative samples are not important sources of error

36. Which of the following statements about interferences in measurement methods is correct?

a. interferences are not important sources of error
b. interferences are chemicals or factors other than the contaminant of interest that result in higher or lower concentrations than the true value
c. correcting results for interferences is a good practice and should be done routinely
d. interferences can be ignored in routine sampling

37. Which of the following statements about accuracy and precision is correct?

a. accuracy describes the variation or scatter among the data
b. precision describes how close a measurement is to the true result
c. a sampling method can be accurate, but imprecise
d. all of the above are correct

38. Which of the following describes the activities needed to ensure that accurate, precise, complete, representative, and comparable data are being collected?

a. standard methods
b. duplicate sampling
c. proficiency testing
d. quality assurance

39. Which of the following defines a check on a sampling method in which known concentrations are introduced and measured on a routine basis?

a. standard method
b. calibration
c. standard material
d. blank

40. Which of the following statements about quality control activities is correct?

a. standard methods are those that have been tested to determine their accuracy and precision
b. EPA has established proficiency testing programs for radon and asbestos
c. the sample blank refers to the concentration of contaminant that is present in a clean, unexposed sampler
d. all of the above are correct

41. Which method has been most widely used to sample particles and aerosols?

a. adsorption
b. filtration
c. absorption
d. electrostatic precipitation

42. What is a source of systematic errors in sampling?

a. lack of proper calibration
b. incorrect design of the sampling program
c. interferences
d. all of the above are examples of systemic errors

43. Which of the following is an example of a nonregulatory administrative approach to the control of indoor air contaminants?

a. building codes
b. housing codes
c. training of investigators
d. ventilation standard

44. Which of the following is an example of a design and maintenance strategy to control indoor air contaminants?

a. use of safe building materials
b. indoor air contaminant standards
c. public information
d. research and development

45. Which is an example of source control?

a. enclosing asbestos pipes
b. reducing humidity with evaporative coolers
c. opening windows while spraying pesticides
d. using a panel filter to control house dust

46. Which of the following would be least effective in ventilating a new energy efficient home?

a. cross ventilation
b. whole house fan
c. infiltration and exfiltration
d. local exhaust ventilation

47. The roof ventilator is an example of which type of ventilation?

a. simple ventilation
b. cross ventilation
c. supply fan
d. exhaust fan

48. Which of the following statements is correct about air infiltration or leakage?

a. air infiltration can be effectively reduced through the use of a continuous air or air/vapor barrier
b. a fan pressurization test is one way of identifying air leakage points
c. condensation in cold cavities is a concern if air/vapor barriers are installed improperly
d. all of the above statements are correct

49. Through which of the following does the exchange of outdoor air with indoor air occur?

a. infiltration and exfiltration
b. natural ventilation
c. mechanical ventilation
d. all of the above

50. Which of the following must be balanced by an air supply in order to prevent backdrafts if a fireplace is used?

a. supply fan
b. exhaust fan
c. infiltration and exfiltration
d. cross ventilation

51. Which of the following could be added to a central forced-air heating and cooling system to reduce both particulate and gaseous contaminant concentrations?

a. panel filter
b. fresh air connection
c. chemical adsorbent
d. electrostatic precipitator

Examination continues on next page

52. Which of the following contaminants could result from the use of a heat exchanger or evaporative cooler?

a. carbon monoxide
b. carbon dioxide
c. nitrogen dioxide
d. microorganisms

53. Which of the following air cleaning devices can remove respirable particulates with efficiencies of over 99%?

a. panel filters
b. extended surface filters
c. HEPA filters
d. heat recovery ventilator

54. Which of the following contaminants could result from the use of electronic air cleaners?

a. ozone
b. microorganisms
c. carbon monoxide
d. carbon dioxide

55. Which of the following is a control device in which gaseous contaminants are attracted to and retained on the surface of materials such as alumina?

a. ionizing flat-plate filter
b. adsorption device
c. electret filter
d. heat recovery ventilator

56. Which of the following is the most commonly used material for adsorption of gases and odors?

a. alumina
b. sodium carbonate
c. activated charcoal
d. potassium permanganate

57. Which of the following standards/guidelines identifies acceptable levels of indoor air contaminants?

a. National Toxic Release Inventory
b. Uniform Building Code
c. ASHRAE standards
d. NIOSH Criteria Documents

58. Which of the following standards/guidelines identifies acceptable ventilation rates for indoor air environments?

a. World Health Organization Air Quality Guidelines for Europe
b. CABO One and Two Family Building Code
c. Canadian Exposure Guidelines for Indoor Air Quality
d. American Conference of Governmental Industrial Hygienists Guidelines

59. Which of the following statements about ASHRAE's Standard 62-1989 Indoor Air Quality Procedure is correct?

a. acceptable indoor air quality is defined as air that does not have known harmful contaminants and 80% or more of the people exposed do not express dissatisfaction
b. acceptable indoor air quality must be achieved by meeting acceptable concentrations of indoor air contaminants
c. the standard recommends using a safety factor of 1/100 as a preliminary guideline for contaminants that are not specifically listed
d. the standard is designed to provide protection to the entire population, including those who are especially sensitive to chemical exposures

60. Which of the following statements about ASHRAE's Standard 62-1989 Ventilation Rate Procedure is correct?

a. residences are the only buildings to which the standard applies
b. ventilation rates can be achieved only through the use of acceptable outdoor air quality
c. the ventilation requirements are designed to protect healthy adults
d. recirculated air can be used to meet ventilation requirements if the air is treated by contaminant removal equipment

61. Which of the following correctly identifies ASHRAE's 62-1989 outdoor air requirements for living areas in residential housing?

a. 0.35 ach but not less than 15 cfm per person
b. window space of not less than 8% of the habitable floor area, half of which must be openable
c. 1 air change every 30 minutes
d. 0.5 ach of fresh air, if window space is equal to at least 4% of the habitable area

62. Why may ventilation standards/guidelines be inadequate to protect indoor air quality in the U.S.?

a. the housing stock was constructed at different times under different code/ standard requirements
b. some HVAC systems may be poorly maintained and operated incorrectly
c. although adequate openable window space may be available, it may not be used
d. all of the above reasons are correct

63. Why are standards/guidelines for the workplace inappropriate for residential applications?

a. occupational standards are intended to protect healthy adult workers, but not all segments of the population including the old, the young, and the ill
b. occupational standards are based on 8-hr exposures for a working lifetime, not continuous exposures
c. occupational standards generally consider cost and technical feasiblity
d. all of the above are correct

64. Which of the following statements is correct about the Canadian exposure guidelines?

a. the guidelines protect all members of the public, including those who are especially sensitive to chemical exposures
b. the guidelines are written for outdoor air pollution
c. the guidelines protect the public against short-term and long-term effects
d. the guidelines have been developed for over 200 contaminants

65. Which of the following identifies an existing source emission standard?

a. formaldehyde from particleboard and plywood in manufactured housing
b. asbestos from vinyl asbestos floor tile
c. xylene from latex paints
d. radon from gypsum board

Examination continues on next page

66. **Which of the following statements about survey forms is *not* correct?**
    a. survey forms must ensure the collection of consistent data
    b. form design is not difficult
    c. the confidentiality of collected information must be preserved
    d. survey forms can include questionnaires with yes/no questions or open-ended questions

67. **Which of the following should be included in a residential inspection?**
    a. educating the client about indoor air problems
    b. administration of a health/symptom instrument
    c. a systems evaluation of the residence
    d. all of the above are correct

68. **Which of the following statements about record-keeping is false?**
    a. inspection data should be written in a notebook and then transferred to data sheets in the office
    b. information should be recorded at the time it is taken
    c. bias can be reduced by using standard forms
    d. record-keeping should be limited to collecting information during sampling and analysis

69. **Which of the following is *not* important when obtaining data on health effects?**
    a. smoking history
    b. occupational history
    c. caffeine intake
    d. all are important

70. **Which of the following is a parameter that should be part of the site evaluation?**
    a. amount of sunlight reaching the house
    b. annual rainfall
    c. geology and soil
    d. annual ambient temperature

71. **Which of the following should be thoroughly evaluated in a walk-through?**
    a. electrical wiring
    b. plumbing system
    c. HVAC system
    d. amount of storage space

72. **Which of the following statements about measuring contaminants during an inspection is correct?**
    a. carbon dioxide and carbon monoxide should always be measured
    b. average and worst case exposures are needed to fully evaluate potential health effects
    c. samplers should be located away from the center of a room to avoid problems with infiltration and exfiltration
    d. if a contaminant is suspected based on the health survey, its presence should be measured before doing anything else

73. **Which of the following does not explain why it is difficult to evaluate measurement results?**
    a. there are many different types of houses
    b. the variability in human response to contaminants
    c. the lack of consensus on standards and guidelines
    d. the similarity of symptoms resulting from exposure to indoor air contaminants and stress

74. Which of the following describes a controversial condition in which some subset of the population is said to be especially sensitive to a broad range of chemicals at low levels of exposure?

a. mass psychogenic illness
b. multiple chemical sensitivity
c. sick building syndrome
d. none of the above

75. Which of the following statements about communication of results is correct?

a. preliminary results should not be given because of liability problems
b. a written report should always be prepared even if a verbal report is given
c. if remedial services are needed, the investigator should recommend a contractor
d. if no cause of the problem is apparent, the investigator should suggest a referral of the client to a mental health agency

76. Which of the following is a basic element of effective communication?

a. listening
b. caring
c. documenting
d. all are correct

77. How will the investigator ensure that correct information is obtained?

a. repeat information back to the client
b. use standard forms
c. use a systematic approach
d. all are correct

78. What is the first step in establishing an indoor air program?

a. set the program objectives
b. obtain the necessary funds
c. define the need for the program
d. hire the staff

79. Which is *not* an element of a major program objective?

a. specify the intended result
b. provide a target date for completion
c. stick to the original plan, regardless of circumstances
d. anticipate obstacles

80. Which is a source of information for estimating program costs?

a. personnel specialists
b. equipment vendors
c. indoor air staff in other agencies
d. all of the above

81. What actions should the program manager take when providing information on the indoor air program to the news media?

a. decline to comment on controversial issues
b. strive for the maximum publicity
c. anticipate the impact of the program
d. refer all questions to superiors

82. What will assist the program manager in proper evaluation of the program?

a. program manager should closely supervise all the employees
b. program manager should be technically expert in all aspects of indoor air quality
c. program manager should have adequate information about whether the objectives were attained
d. program manager should not share sensitive program information with the public

83. What actions should be taken if major program objectives are not being achieved?

a. those responsible should be dismissed
b. the program manager must diagnose the problem and take corrective action
c. it would be unfair to charge fees for services
d. it should not be of concern because indoor air quality is still a new issue

Examination continues on next page

84. What would help in attaining a major program objective?

a. build in a larger timeframe than necessary
b. develop an accompanying action plan
c. have a tough-minded program manager
d. gain the support of people in the news media

85. What should a program manager do before implementing a new indoor air program?

a. ensure that there is popular support for the program
b. work out administrative relationships with other supporting departments
c. attend as many management training courses as possible
d. avoid becoming involved in internal politics

86. Which of the following is important when deciding whether to include enforcement as part of the indoor air program?

a. de-emphasize this aspect with the news media
b. place equal emphasis on education
c. ensure that the proper legal and administrative support is in place
d. all of the above are correct

ANSWER SHEET

In order for us to accurately score and return your examination, you must complete all information requested. Print your name as you want it to appear on your certificate of completion.

Name ______________________________

Address ______________________________

City ______________ State ________ Zip ________

Phone Home (______) ______________________

Work (______) ______________________

Title of Module ______________________________

Time Spent Studying Material ______________________

Time to Complete Final Exam ______________________

HOW TO USE THE ANSWER SHEET

1. Place an X through the letter that corresponds with the correct answer for each question.

   Example:
   A X C D

2. If you change an answer, be certain that the change is clearly indicated.

3. Do not make a copy of this answer sheet. Remove this page and answer sheet and send, along with a check for $7.50 made payable to NEHA, to:

   National Environmental
   Health Association
   720 Colorado Blvd.
   #970 S. Tower
   Denver, Colorado 80222

ANSWER SHEET

1.	A	B	C	D	23.	A	B	C	D	45.	A	B	C	D	67.	A	B	C	D
2.	A	B	C	D	24.	A	B	C	D	46.	A	B	C	D	68.	A	B	C	D
3.	A	B	C	D	25.	A	B	C	D	47.	A	B	C	D	69.	A	B	C	D
4.	A	B	C	D	26.	A	B	C	D	48.	A	B	C	D	70.	A	B	C	D
5.	A	B	C	D	27.	A	B	C	D	49.	A	B	C	D	71.	A	B	C	D
6.	A	B	C	D	28.	A	B	C	D	50.	A	B	C	D	72.	A	B	C	D
7.	A	B	C	D	29.	A	B	C	D	51.	A	B	C	D	73.	A	B	C	D
8.	A	B	C	D	30.	A	B	C	D	52.	A	B	C	D	74.	A	B	C	D
9.	A	B	C	D	31.	A	B	C	D	53.	A	B	C	D	75.	A	B	C	D
10.	A	B	C	D	32.	A	B	C	D	54.	A	B	C	D	76.	A	B	C	D
11.	A	B	C	D	33.	A	B	C	D	55.	A	B	C	D	77.	A	B	C	D
12.	A	B	C	D	34.	A	B	C	D	56.	A	B	C	D	78.	A	B	C	D
13.	A	B	C	D	35.	A	B	C	D	57.	A	B	C	D	79.	A	B	C	D
14.	A	B	C	D	36.	A	B	C	D	58.	A	B	C	D	80.	A	B	C	D
15.	A	B	C	D	37.	A	B	C	D	59.	A	B	C	D	81.	A	B	C	D
16.	A	B	C	D	38.	A	B	C	D	60.	A	B	C	D	82.	A	B	C	D
17.	A	B	C	D	39.	A	B	C	D	61.	A	B	C	D	83.	A	B	C	D
18.	A	B	C	D	40.	A	B	C	D	62.	A	B	C	D	84.	A	B	C	D
19.	A	B	C	D	41.	A	B	C	D	63.	A	B	C	D	85.	A	B	C	D
20.	A	B	C	D	42.	A	B	C	D	64.	A	B	C	D	86.	A	B	C	D
21.	A	B	C	D	43.	A	B	C	D	65.	A	B	C	D					
22.	A	B	C	D	44.	A	B	C	D	66.	A	B	C	D					