

INDOOR AIR QUALITY: A SYSTEMS APPROACH

THIRD EDITION – JANUARY, 1998



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**
4201 Lafayette Center Drive
Chantilly, VA 20151-1209

INDOOR AIR QUALITY: A SYSTEMS APPROACH

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NATIONAL ASSOCIATION, INC.**

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FOREWORD

As the Indoor Air Quality (IAQ) industry has changed over the years, and with coming changes on the horizon, the SMACNA contractor needs to be equipped to handle this every changing market and opportunities. The SMACNA Building Services Task Force was formed to address these issues and develop a manual that provided the hands-on application that would be required by today's contractor.

This "state-of-the-art" manual should identify IAQ problems as they are currently defined, the methods and procedures used to solve them, the equipment and instrumentation that is used, and the changes that must be made to the building and the building HVAC systems.

This publication is intended to present in a clear and concise, yet comprehensive manner the sources of pollutants, methods of control, and the management techniques necessary to maintain acceptable indoor air quality in today's market. The SMACNA Building Services Task Force recognizes that this new manual contains the latest information available, and will need to be revised or updated as newer information becomes available.

SMACNA wishes to thank the efforts and funding of the National Energy Management Institute in assisting in the development of this manual for the industry.

SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.



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PHASE I

FUNDAMENTALS OF INDOOR AIR QUALITY

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CHAPTER 1

INTRODUCTION TO INDOOR AIR QUALITY

Phase I of this manual introduces the fundamentals of indoor air quality (IAQ) concerns and problems. It covers a brief history leading to the current level of concern over this worldwide issue. The five chapters in Phase I include:

- a. Basic indoor environmental concerns.
- b. Building environmental systems and how they contribute to the problems.
- c. Basic testing and sampling.
- d. Solutions to some IAQ problems.
- e. Other sources of indoor air problems.

Phase I includes material which most building owners and managers should know in order to work with you to contract for the needed indoor air quality preventive measures and problem solving.

1.1 INDOOR AIR QUALITY

1.1.1 Early IAQ

The first attempts to control the quality of indoor air were repeated often as man developed more complex dwellings and a greater need and desire for ventilation. Until mechanical systems were available to ventilate buildings, man relied on natural ventilation to meet those needs. Caves with smoke exits, castles with cleverly designed fireplace drafts, and the American Indian teepee were examples of early methods to control the indoor environment.

Natural ventilation had many of the advantages we look for today in assessing the ability of mechanical ventilation systems to supply sufficient ventilation air. One of the most significant advantages was the constant supply of fresh outside air which was also low in carbon dioxide concentration and other internally introduced contaminants.

1.1.2 IAQ Concerns

The health of the occupants in a facility should be the primary concern of the building management team responsible for IAQ. We will see later how this is also beneficial in support of evidence against claims of negligence resulting from IAQ problems.

Concern for the health of the occupants shows due diligence in pursuit of a healthy environment. The same concern will result in higher levels of work output.

Several studies have shown that work productivity, often spoken about in abstract terms until now, can rise by as much as 10% if the indoor air is clean and perceived to be healthy. On the other hand, if the indoor environment is poor, or is perceived to be below acceptability, work productivity is certain to drop.

In a 1981 report, the National Research Council identified four basic reasons for increasing concerns about indoor air quality:

- a. Energy conservation efforts have tended to reduce the amount of ventilation available to dilute indoor contaminants to acceptable concentrations.
- b. Techniques for measuring occupant exposure to contaminants at low concentrations have improved.
- c. Widespread sources of contaminants exist indoors and outdoors.
- d. Awareness by the general public of the impact of indoor air quality on health and well-being has increased.

Understanding of the importance of indoor air quality has increased significantly during the last decade. Demographic studies have shown that current United States populations typically spend up to 90% of their lives indoors.

Studies also indicate that indoor concentrations of contaminants are frequently higher than corresponding outdoor values. Thus, exposures to indoor contaminants may have more impact on public health and well-being than outdoor exposures.

1.1.3 IAQ Definitions

Generally, indoor air quality may be defined as the nature of air that affects the health and perceptions of the occupants. This definition incorporates the concept of health in the constitution of the World Health Organization (WHO): "Health is a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity."

IAQ concerns in the office, educational, and institutional environment differ from industrial indicators of acceptability. The differences are primarily reflected in threshold limit values (TLV's) which were developed to help maintain the ability of an adult population to perform physical work in an industrial environment. TLV's are the limits accepted by the



American Conference of Governmental and Industrial Hygienists (ACGIH) beyond which health and performance can be affected. Complaints of poor indoor air quality occur in non-industrial spaces at concentrations much lower than the TLV's.

According to the American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.'s (ASHRAE) Standard 62–1989, acceptable air quality is: “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.” This definition implies compliance is required with both objective criteria (*i.e.*, measured concentrations of contaminants) to prevent illness and subjective criteria such as individual perceptions and comfort.

The term “sick building syndrome” (SBS) is sometimes used to describe cases in which building occupants experience acute health and comfort effects that are apparently linked to the time they spend in the building, but in which no specific illness or cause can be identified. The complaints may be localized in a particular room or zone or may be widespread throughout the building. Many different symptoms have been associated with SBS, including respiratory complaints, irritation and fatigue.

“Building-related illness” (BRI) is a term referring to illness brought on by exposure to the building air, where symptoms of diagnosable illness are identified and can be directly attributed to environmental agents in the air.

1.2 IAQ STANDARDS

ASHRAE, recognizing the public concerns about IAQ, published the “Standard for Natural and Mechanical Ventilation” in 1973, ASHRAE Standard 62–1973. This document specified both minimum and recommended outdoor air flow rates to obtain acceptable IAQ for a variety of types of spaces and uses. No mention was made of the nature of indoor air pollutant sources and their impact on IAQ.

Two years later ASHRAE published Standard 90–1975, “Energy Conservation in New Building Design.” Standard 90–1975 stated that the minimum air flow rates were to be used for design purposes only. This eliminated the established recommended ventilation values and caused concern that the quality of indoor air would be compromised. In 1978, a standards review committee addressed the question of

whether these minimum values could be defended under all conditions. The result of this study was Standard 62–1981, “Ventilation for Acceptable Indoor Air Quality.” This standard recommended outdoor air flow rates for spaces with and without smoking. The 1981 version of Standard 62 also introduced an alternative IAQ procedure to permit innovative, energy conserving ventilation practices. The procedure specified both pollutant concentration and odor acceptability criteria for determining the quality of the indoor air. This departed from the traditional prescriptive manner of recommended ventilation rates. This procedure allowed design engineers to use any amount of outdoor air for ventilation as long as the indoor air contaminant levels were maintained below the specified limits.

The “prescriptive method” of specifying ventilation rates for each space or type of occupancy provides specific airflow rates during the construction and commissioning process. However, it provides no assurance that IAQ will be acceptable when the building or space is occupied. The “air quality” method provides a greater degree of results-orientation for the occupied building but does not provide clear, specific design criteria for the design engineer.

The current version of Standard 62 was released in 1989. Under development and review since 1983, ANSI/ASHRAE Standard 62–1989 is now used as the base design document by many codes and recommendations throughout the United States. Standard 62–1989 encompassed many changes over the previous versions of the standard. The distinction between smoking and non-smoking spaces is removed and the recommended levels of indoor pollutants have been relegated to the appendices or removed. The recommended pollutant levels are 1/10 of the ACGIH TLV's. The residential ventilation recommendation was changed from 10 cubic feet per minute (cfm) per person to 0.35 air changes per hour (ach). Standard 62–1989 retains methods for IAQ based on air quality and ventilation.

1.3 ENERGY CONSERVATION VS. IAQ

1.3.1 Energy Usage

For the last two decades, the uncertain future of energy resources has had a major influence on the design and operation of buildings throughout the world. Prior to the oil embargoes of the early 1970's, the objectives of designers and managers of buildings (commercial and residential) were to maximize occupant comfort with centralized heating, ventilating, and air conditioning systems. With little concern for energy costs, lighting in many buildings was increased as well.

Since the oil issues and concerns over the accessibility of supplies from the Middle East, several factors have arisen to affect the way buildings are managed:

- a. Costs of owning and operating buildings have increased.
- b. Shortages of fossil fuel products have occurred repeatedly in the United States and in other “high fuel usage” countries.

As a result of these factors, change in the design and operation of buildings have occurred throughout the world. Some of these changes have certainly been beneficial, such as reduced energy consumption and operating costs. Unfortunately, some of the changes have caused discomfort or have had other negative effects for the building occupant due to indoor contaminants. Due to health concerns and efforts to maintain and enhance occupant productivity other factors must be considered during the energy and ventilation design steps for a building. Designers must remain aware of the impact of IAQ on the occupants and must account for the chemical products used in the facility after it is occupied.

1.3.2 Building Energy Management

Since the early 1970's, the concept of building energy management has evolved into a significant discipline in the United States. The importance of its practice has been recognized as a means to reduce the depletion of natural resources and the dependence on foreign fossil fuel supplies and routes of delivery. Therefore, building energy management contributes to national goals of stability, security, and independent strength. Building energy management has also been recognized as a means to reduce or control operating budgets of individual facilities.

A key factor in reducing energy consumption to manage the environmental comfort of a building is the cost of operating the facility. However, without additional impetus to reduce fuel usage most building owners will maintain the appropriate comfort level and pass along any additional costs to their tenants or clients as required. The government's *Emergency Building Temperature Restrictions* of the late 70's provided the added impetus for owners to dramatically cut back on comfort maintenance.

The development of newer energy management strategies through creative use of the controls and systems in a building have helped to control the reductions of ventilation as a prime strategy. Still, many buildings

designed and constructed during this period are only capable of delivering 5 cfm of outside air per person to the occupied spaces.

Efficiencies in building equipment and loads have improved and have helped to reduce the need for added capacities. At the same time, more equipment has been added in the form of computers, printers, copiers, and more. These added loads have dictated that buildings have excess capacity and that delivery systems are designed for higher peak loads.

Air conditioning strategies for both heating and cooling cycle have improved along with equipment efficiencies. These strategies help to reduce peak capacity since comfort management is typically the highest energy user in non-industrial facilities. Buildings are now built with a tighter envelope (with positive and negative results) to reduce the need for heating and cooling.

1.3.3 Conclusion

One of the key issues to arise from the above energy reduction strategies and equipment design criteria is reduced attention to indoor environmental conditions. Also, since equipment and systems typically have lower reserves, it is often difficult for managers to control the facility during extreme conditions. Building furnishings release pollutants due to chemicals used during the manufacturing and processing of man-made materials. This further complicates the IAQ problems arising from lowered ventilation.

With media attention to IAQ problems on the rise and measurement methods improving, more occupants and building managers are aware of the dangers and problems of poor indoor environmental conditions.

1.4 OCCUPANT RESPONSES

1.4.1 Stresses

The fundamental objectives of environmental control are to provide occupant comfort and prevent exposure to unhealthy contaminants. Occupant complaints do not necessarily arise from intense exposures to one specific contaminant but from more gradual or subtle exposures to a combination of conditions in the building. Occupant complaints about building conditions generally fall into the following three classes:

- a. Perceived conditions causing real physiological strains. These include stressors such as warm or cold drafts, odors, environmental tobacco smoke, improper lighting, and noise.



- b. Conditions not perceived by the occupants which cause physiological strain. These stressors include odorless gasses and vapors, particulates below the human detection level, and gaseous compounds below the odor threshold.
- c. Conditions which are perceived to be problems but which would not normally cause physiological stress. Examples include the work/management climate and job satisfaction. Some real physical condition issues, such as low noise levels or variations in lighting, can also fit this category when they occur in combination with other conditions.

1.4.2 Comfort Demands

Comfort demands are based on meeting the needs and expectations of the occupants of the building. The occupants use normal human sensory inputs (sight, sound, smell, touch, and even occasionally, taste) to determine their own perceptions of their environment. Most of the environmental factors we consider to be components of IAQ problems are sensed by touch and smell. Other stressors, such as excessive or insufficient lighting or high noise levels, affect those respective sensory organs.

As indicated above, some of these stressors cause physiological strains while others, such as job-related stress, predispose the physical strains. If these stressors, which stimulate the four basic types of sensory receptors (*i.e.*, olfactory, auditory, thermal, and visual), are controlled within certain limits, resultant physiological strains (*e.g.*, vasomotor control) can be pleasant or comfortable to the occupant. However, if acceptable limits are exceeded, if the perceived stressors are not recognized (*e.g.*, strange odors), or if psychosocial stressors are significant, complaints of discomfort will usually result. Symptoms associated with unacceptable stressors include headaches, nausea, and fatigue from heat, glare, noise, and odors; eye irritation from low humidity, glare, and odorous compounds; and throat and respiratory irritations from cold drafts, low humidity, and odorous compounds. Thus, to provide comfort, simultaneous control of the four basic environmental stressors is required.

1.4.3 Productivity

According to the “Productivity and Indoor Air Environmental Quality Study” (National Energy Management Institute, (NEMI), 1993) and many authors and building management professionals, improvements in air quality provide a high return on investment from

productivity gains, health care savings, and energy reductions.

The conclusion of this study indicates an average payback (the time required to recover the cost of a change) of 1.6 years from productivity benefits of improved indoor environmental quality. Some payback periods can be as short as seven months according to the study which also notes monetary benefits to the building occupant and long term psychosocial benefits in the workplace as additional gains from environmental improvements.

Based on productivity gains of 1.5% in the average building and up to 6% in sick buildings, the study concludes that there is a potential \$55 billion benefit in the United States alone.

Responsible building owners and managers who are proactive in dealing with indoor air quality issues through regular IAQ inspections and preventive measures are most likely to benefit from these productivity gains.

1.5 LIABILITY CONCERNS

Liability for poor IAQ can begin at the design of a building and continue through the life of the facility. Large court settlements and media attention contribute to growing liability concerns.

Proactive management is the best tool for the building owner who is interested in reducing or avoiding liabilities for IAQ problems. Health and safety standards, local code activity often based on nationally accepted standards (*e.g.*, ANSI/ASHRAE 62–1989), and federal agency efforts can guide the building owner.

Liability insurance costs have risen rapidly in the last few years and continue to escalate for those involved with building design, construction, and operation. Worker’s compensation claims, employee walkouts, class action suits, lease agreement violations, and medical claims have all been part of recent legal actions. Growing awards by the courts for settlements in these claims in addition to the productivity benefits noted above are the driving forces for implementing environmental improvements.

There are other liabilities to the building manager in addition to the potential for legal actions in the case of poor indoor air quality. Loss of tenants in leased spaces is one major concern. A building, or section of a building, which has IAQ problems will be more difficult to lease or may not command the same price as if the area had no problems. Owners are becoming

more proactive in preventing and solving IAQ problems in tenant spaces than ever before due to the potential for lost revenues and the difficulty in leasing a space.

1.6 IAQ POLICY

Proactive building owners will have an IAQ policy in effect for their facilities. An IAQ policy will provide evidence of “due diligence” in caring for the occupants of a facility if the issue ever does come to a court case. An IAQ policy provides a working goal for the building management staff when no local, state, or federal codes or standards cover the situation. The policy should prevent problems from occurring or provide a means of solving them quickly.

The success of the IAQ policy is dependent on occupant education. If the occupants know what the policy is and how it affects their daily lives in the building, they are more likely to support the policy and IAQ team. One reason people complain is that they do not understand what is happening. A proactive building manager can help them to understand what is happening by ensuring they are fully aware of the IAQ policy.

One of the most effective steps to help improve IAQ is to actively promote the indoor air quality program by getting all of the occupants involved. The policy should be published in a company newsletter or in some other fashion that ensures that all of the occupants will be aware of its components.

The vocabulary of indoor air quality should also be promoted. Let the occupants know that CO₂ itself is not necessarily injurious to their health. Once understood, a CO₂ limit for the building may be openly promoted. Without this sort of knowledge, building occupants have been known to regularly confuse CO₂ and CO – a very dangerous mix-up.

Prevention is always less costly than the cure. This is as true with air quality as with any other issue. Preventing IAQ problems can return the investment many times over. There will be fewer complaints and problems to resolve, and the corporate productivity will increase as a result of the improved environment.

In addition to the testing, cleaning, system maintenance, and ventilation, there are a few items that should be addressed in an effort to prevent IAQ problems. Two of the most important are:

- a. Open promotion of the corporate IAQ policy.

- b. Education of the occupants on their responsibilities for helping to maintain the working or living environment.

1.7 IAQ OPPORTUNITIES

Indoor air quality represents an opportunity for SMACNA members to furnish services which build on their current business strengths and provide clients with much-needed expertise towards the prevention or resolution of IAQ problems.

The environmental management of a modern, mechanically ventilated building is a complex balancing act. The building operations staff must monitor the comfort conditions and needs of the occupants, the energy usage of the entire structure (or campus), and stay in tune with current local, state, and federal requirements for environmentally healthy and safe conditions. The HVAC industry brings together the skills necessary to properly install, service, and modify air handling systems to help ensure this healthy environment.

A mid-1996 nationwide study showed environmental management business opportunities to be the second fastest growing industry in the United States. With an annualized growth rate of 4.8%, the possibility of success for a new business or an added business segment to an existing business is higher than for any other business, with the exception of the high-tech communications industry. Environmental management includes all facets of helping people enjoy a better, healthier place in which to live and work. Indoor air quality management, systems, controls, testing, and problem resolution may be one of the faster growing segments of this overall business.

Table 1-1 shows some of the typical opportunities for changes in control strategies used in light of severe energy management and subsequent “tight” building problems. These opportunities include system rework and minor changes in equipment, ducting, and controls.

Most building energy management strategies have an impact in IAQ. In some cases they may improve environmental conditions and in other cases they may cause degradation of the indoor environment. Degradation from any source may result in lowered productivity for the owner/operator of the building and in the most serious situations, may cause severe discomfort and sickness for the occupants.

The proactive building operations manager, working with SMACNA contractors, should determine the



correct energy management strategy, systems, and key environmental objectives. The end results of building improvements are lowered operating costs and higher productivity. As an added bonus, better employee (occupant) health may also lead to lowered

employee benefit costs for some owners. Reducing energy usage helps to preserve fossil fuel reserves. Reducing IAQ problems helps to eliminate litigation for those conditions and symptoms further reducing the building owner's operating and risk costs.

CONTROL STRATEGY			
Item	Comment	Indoor Environmental Impact	Energy Saving Potential
Improved ventilation efficiency	Use care in selecting locations of supply and return air devices.	Improved thermal comfort, reduced occupant exposure to airborne contaminants, reduced noise.	Reduced fan power requirements, reduced outside air conditioning requirements.
Air quality feedback control	Use a carbon dioxide or other air quality sensor to control ventilation.	Improved, more consistent, comfort during variable occupancy.	Reduced energy consumption during partial load conditions or during unoccupied periods.
Optimization control	Utilize a dynamic selection of dilution or filtration, air supply patterns, and acceptable conditions.	Improved comfort during variable occupancy, process (building function) loads, and outdoor conditions.	Optimized energy savings for variable thermal and contaminant loads.

Table 1-1 Energy Management Strategies and Environmental Impact

CHAPTER 2

INDOOR ENVIRONMENTAL CONDITIONS

2.1 INTRODUCTION

There are many factors in the environment inside a building which affect the occupants. While most of the current media attention is focused on air quality specifically, other factors either cause totally independent problems or act synergistically to worsen existing IAQ problems. These building environmental factors consist of noise, odors, lighting, comfort level, and social conditions in the workplace. When these areas become problems, they add to the perceived problem factors including ventilation (or carbon dioxide level), draftiness, temperature and humidity, and gaseous and particulate contaminants.

Problems can also be caused by contaminants which are totally unnoticed by the occupants. Airborne or waterborne micro-organisms can cause illness. Toxic or carcinogenic substances in the occupied environment can cause long-term health problems and death. Radon from gases entering through substructures can be carcinogenic over long periods of time. Problems may result in litigation against the building owner, operator, and designer.

Not all occupants perceive, observe, or react to, environmental conditions in the same manner. Even serious conditions such as disease producing microbial contamination in a building is likely to affect only a small percentage of the occupants. One given occupant might also suffer from differing symptoms with the same exposure to the same contaminant at different times. Since poor IAQ conditions affect people in markedly different ways, it is difficult to pinpoint specific problems by merely asking questions of the occupants. Not all occupants in a building will even agree on what is an acceptable temperature and humidity level.

No one has yet fully explained the synergistic effects of all of the factors noted in Table 2-1. Certainly though, if one of the factors has a negative impact, then it is possible (some researchers say “likely”) that building occupants will perceive the other factors to be problematic in some way. There is a potential impact on any one building factor due to changes in any other building environmental condition. If occupants do not understand all of the factors which affect them on a day-to-day basis, they are likely to complain about those they do not understand.

Since there is so much media attention focused on indoor air quality, occupants will complain about IAQ problems when the real culprit is some other condi-

tion in the facility. The term “sick building syndrome” (SBS) is often misused by the general public as well as the press. Sick building syndrome is a very specific term which defines a condition in which more than 20% of the occupants in a building are not satisfied with the building environmental conditions.

SBS can be caused by any one or more of the environmental or psychosocial factors noted in Table 2-1. One factor alone can cause SBS if the condition is sufficiently severe. The problem can be worsened (or occur more often) if more of the environmental conditions noted above appear in combination.

SBS can happen in any size facility. The most common occurrence is in large office facilities which suffer from overcrowding, regular renovation activity, and lack of care. This is one more reason for building owners to become proactive in their approach to preventing IAQ problems.

2.2 THERMAL ENVIRONMENT

People have a physiological and psychological control system which maintains a healthy human body at the proper temperature. ASHRAE has published “Thermal Comfort” Standard 55, to describe these conditions. The deep body temperature range is from 97.7 to 99.5°F (36.5 to 37.5°C), while skin temperature in a healthy adult might range from 91.4 to 97.7°F (33.0 to 36.5°C). If the body has trouble maintaining these temperatures it will resort to dilation (reduction) of the surface blood vessels to reduce temperature loss (or gain) and may begin shivering in extreme cases of cold. These physiological adjustments are perceived as uncomfortable and if they occur in a location where the person expects a better comfort level, will lead to complaints.

The thermal environment is a combination of sensible heat (*e.g.*, overly warm or cold walls), relative humidity (RH) and latent heat, and the air movement at the working location. Each occupant in a building will perceive the thermal environment differently. The range of humidity for an office environment should generally be based on the assumption that people are dressed in typical clothing for their activities. It should be adjusted for light activity or for people who are sedentary. This range is typically from 30% to 60%. The RH range should be maintained in winter and summer. RH below 30% will cause discomfort from dryness. RH above 60% over a prolonged period will cause discomfort due to lack of evaporation of sweat in even light activities.



Factors Directly Affecting Air Quality	Factors Affecting Other Perceptions
• temperature • temperature variations • humidity and moisture • wet surfaces • air movement, draftiness, stuffiness • gaseous and particulate contaminants • entrained dust and dirt	• lighting • noise • furnishings and surroundings • social interaction • building vibration or movement • crowding and personal space • odors from personal products • building functional byproducts

Table 2-1 Factors Affecting Occupant Perceptions of Building Environment

Temperatures (dry bulb) should be maintained between 74 and 80°F (23.3 and 26.7°C) in summer if the RH is at 30% and from 72 to 78°F (22.2 to 25.6°C) if the RH is 60%.

The comfort concerns associated with temperature and humidity must be balanced against the risks. For example, maintaining winter RH at the low end of the range to prevent window condensation or fungal growth may lead to problems such as itchy eyes and nasal irritation in average occupants. Some studies suggest that higher temperatures lead to a greater number of IAQ complaints. If temperatures are maintained at the low end of the comfort range during winter (in most North American cities) the indoor RH will remain at 30% or higher.

The most typically used parameter to define the comfort level of the indoor environment is dry bulb temperature. However, as commonly accepted as this practice is, there are instances where the latent heat in the moisture in the air or the air velocity can degrade the effect of otherwise comfortable temperatures. Radiant gains or losses near insufficiently insulated walls or windows can cause the same type of problem. Discharging air at too high of a velocity (or too low in temperature) can cause local discomfort in rooms where the average temperature is fully satisfactory to a majority of the occupants.

All of these environmental factors are considered basic to the issues of proper building management and good indoor air quality. Negative effects in the environment can create cumulative results in terms of discomfort.

2.3 LIGHTING

Lighting which is not sufficient for the task or which causes glare on work surfaces or computer monitors is an environmental stressor. Artificial lighting must

meet the occupants needs in terms of light intensity and color. Lighting which is poorly arranged causes the same problem as insufficient lighting. Arrangement problems could be due to repeated changes in the workplace layout resulting in cubicle panels casting shadows on the work surfaces.

Illuminance or light level is measured in foot-candles. The origin of the term is in the amount of light measured one foot from a lighted candle. The range of lighting useful for humans is approximately from 1 foot-candle to 10,000 foot-candles (bright sunlight). As light levels increase above 25 foot-candles, there is little improvement in the human ability to see or read except for persons with inadequately correct vision.

Light quality includes color-temperature, glare, reflections, contrast, and distribution. Lamps which are the correct color in one space will be entirely inappropriate in another. For example, fluorescent bulbs for washrooms, and residential kitchens may be on the “warm” end of the lighting scale and will appear pink when compared to whiter lamps. These “warm” lamps will not provide sufficient light of the proper color for general office work.

Lighting degrades with time as lamps become dirty externally and internally. Lamps and ballasts also fail, leaving some fixtures with fewer than the designed number of working units. Lighting checks should always be done with a calibrated light meter (measuring foot-candles) at the working surface. With this type of check, the building owner can also verify that lighting is uniform throughout the work area. Extreme differences in light levels also lead to personal discomfort and complaints.

Lighting which fails to meet any one of the criteria considered comfortable may complaints from the occupants. This may translate into perceived air quality complaints since one of the most typical symptoms

of poor lighting is itchy, red eyes; also one of the most common symptoms of high particulates in the air.

2.4 NOISE

The amount and type of noise are other environmental factors which affect how people perceive the quality of their workplace. Noise problems can interfere with work tasks, cause difficulty with otherwise normal, speech communication, and create problems of annoyance and irritation for the employees and visitors in a building.

The parameters of noise which can result in the most negative impact on occupants are time variations, intensity, and frequency distribution. Each of these may have different effects depending on the nature of the work being done in the space, the age and hearing ability of the occupants, and the level of other physiological stressors in the space.

Time variations are a problem because people tend to adapt to, and accept, noises which are relatively constant for extended periods of time. Noises with frequent variations in intensity or frequency distribution cause problems with speech communication and are extremely annoying to workers who are involved in quiet work tasks.

Frequency distribution describes the intensity of the noise in terms of each frequency component within the range of human hearing. Human hearing range is generally accepted as being between 20 and 20,000 hertz. Noises with nominally equal distributions across a wide range of frequencies are less objectionable than noises with high levels at one, or a few, frequencies.

For building noise management, two terms are important. The first is "broadband" noise. Broadband noise has relatively equal levels over a wide range of frequencies and is sometimes used as a background noise in offices. Broadband noise used in this manner, with carefully defined and controlled output levels, is called "white" noise. The second term is "tonal" noise which defines noise with one distinct frequency component overpowering the rest. Tonal noise can be extremely irritating and generally is not tolerated by occupants at even low intensity levels. Broadband noise can be tolerated at much higher levels than tonal noises.

Noise measurements are made and stated in three standard forms for the types of noise encountered in buildings.

- a. The "third-octave" method tests for the intensity of noise in 27 frequency bands over the nine octave, human hearing range. This method closely emulates the ability of the human sense of sound to distinguish intensity differences in adjacent bands. If frequency-intense distributions are similar in adjacent bands, the occupants of a building will hear tonal noise.
- b. "Octave-band" measurements indicate the intensity values for noise divided into the nine octaves in the hearing range. Octave-band measurements are the desired method of specifying noise acceptability (over a broad spectrum) in all environments.
- c. "A-weighted" noise measurements are the most common as the instrument is indicating an intensity level with one measurement. The type of instrumentation required is commonly available at electronic supply houses. If noise levels are nearly balanced between the octave bands, the a-weighted method of measurement will approach the third-octave method as a parallel to the intensity levels sensed by human hearing.

Noise in HVAC equipment can be any of the types noted above. The most common cause of noise in air handling systems comes from high air velocities in ductwork or through diffusers and other components. Motors and fans also cause noise which can be objectionable if not properly contained. Cooling towers cause noise externally and can be a source of problems to neighboring facilities. Noise below hearing frequencies, or at hearing thresholds, can be caused by improperly mounted motors causing floor, wall, or plenum vibrations. Fan noise and pressure-change movements in ductwork can be carried to the occupied space through the ductwork itself. Ductwork which is not insulated carries fan, and other, noises better than insulated ductwork.

2.5 ODORS

The human sense of smell is not well understood but is extremely capable in detecting certain contaminants in the air. An average person can detect as little as 0.00047 ppm of hydrogen sulfide in the air being breathed.

At their odor threshold most contaminants normally encountered in workspaces are still well below the Occupational Safety and Health Administration (OSHA) limits. The OSHA limits in this case are the Time Weighted Average (TWA) for an 8 hour expo-



sure period, usually annotated TWA8. Concentrations of a contaminant substance in the air at or above its odor threshold, but still below the TWA8 limits, can lead to complaints from the occupants about odors.

Individual sensitivities may vary widely. An odor threshold is defined as the level of concentration at which 50% of the unadapted population will notice the foreign substance. In this definition, ASHRAE also states that adaptation to odors can occur in as little as 15 minutes. Beyond that time, odors become less noticeable. Humidity levels and individual conditions, such as colds, headaches, and longer term illnesses, can also cause sensitivity to vary from the threshold norms.

Sensitivity to odors is not a linear response in humans. The sensitivity formula is a power function:

$$S = kC^n$$

where

- S = Sensitivity
- k = Constant; depends on the conditions and the individual
- C = Concentration; level of the contaminant (typically given in mg/m³)
- n = ~ 0.6

The sensitivity, therefore, does not increase as rapidly as the concentration level with a power of 0.6 in this

equation. A very simple example helps to point this out. If someone near you peels an orange you are very likely to notice the odor immediately. If several more people also peel oranges shortly after, you are unlikely to notice the odor from the additional orange vapors in the air.

Odor thresholds and exposure limits (such as OSHA's TWA and NIOSH's Permissible Exposure Limits) do not necessarily match. Table 2-2 shows a range of contaminants which can occur in non-industrial workplaces and in residential buildings. The table compares the odor threshold for the contaminant with commonly accepted limits for the same chemical elements or compounds.

Note also from Table 2-2 that the boiling points of most of these contaminant gasses are below normal occupied space temperatures. This indicates the element or compound will be a gaseous vapor at room temperatures.

It is desirable that the odor thresholds of dangerous chemicals be below their danger level. Chemical gasses which can be either toxic or explosive at concentrations below the odor threshold often have chemical compounds added to them to make them detectable by our sense of smell before the concentration level reaches safety or health limits.

Contaminant	Odor Threshold		OSHA TWA8 Limit		Boiling Point
	(mg/m ³)	(ppm)	(mg/m ³)	(ppm)	(°C)
Ammonia	33.0	25.0	38.0	28.5	-33
Benzene	15.0	4.6	5.0	1.5	80
Carbon dioxide	n/a	n/a	9,000.0	4918.0	-78
Carbon monoxide	n/a	n/a	55.0	47.0	-192
Chlorine	0.007	0.002	3.0	1.0	-34
Formaldehyde	1.2	0.9	4.0	3.2	97
Ozone	0.2	0.1	0.2	0.1	-112
Sulfur dioxide	1.2	0.45	13.0	4.9	-10
Toluene	8.0	2.1	200.0	52.0	111
Trichloroethylene	120.0	22.0	541.0	99.0	87

See Appendices for more information on these and other chemicals and compounds which can contaminate occupied areas. Where odor thresholds show not applicable (n/a), the contaminant is normally considered odorless.

Table 2-2 Odor Thresholds for Selected Contaminants Found in Buildings

CHAPTER 3

SYSTEMS AND CONTAMINANTS

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3.1 INTRODUCTION

There are three primary contributors to the sources of indoor air problems: heating, ventilating, and air conditioning systems (HVAC); microbial contaminants; and chemical contaminants.

HVAC systems themselves not only may distribute contaminants which originate elsewhere, but may themselves become sources of contaminants. HVAC systems are also considered a source of IAQ problems when the systems do not supply sufficient outside air to properly ventilate the occupied space. Outdoor contaminants and excess moisture can be entrained by the air system if grilles, filters, and air velocities are not appropriate for the application and environment. Preventive maintenance and a proactive approach to air quality management are important to help reduce IAQ problems arising from HVAC system operation.

Microbial contaminants arise when there is sufficient moisture and a source of nutrients for microscopically small, biological elements to grow. Microbial contaminants can cause allergic reactions in sensitive individuals. Microbials in certain amounts also cause highly objectionable odors even though the contaminant level may not be injurious to health. Odors, as noted earlier, can cause perceptions of IAQ problems and unnecessary complaints to the building management team.

Chemical contaminants can originate anywhere in a facility if someone uses, spills, or disposes of some chemical in the wrong way or in excess of recommended amounts. All buildings today have some collection of chemical around with the potential to become contaminants in the air. The accidental combination of ammonia cleaners and bleach can release chlorine gas which causes skin irritation, itchy eyes, and mucous membrane problems. The combination of chemicals is poorly understood in terms of the types of problems caused for human occupants. The best solution is to keep all chemicals under strict control and to be sure only qualified, trained personnel have access to the chemicals used in any part of the building.

3.2 HVAC DESIGN

The systems used to move and condition the air are a part of all areas of any building which is mechanically ventilated. These same HVAC systems, which serve to help with the issue of ventilation, can also be a part of the origin of the IAQ problems when they

are not properly designed or operated to meet the demands of the facility.

The origins of the IAQ problems noted in the introduction are paralleled with the three methods of solutions to IAQ problems: ventilation, cleaning, and source elimination. The HVAC system serves as the source of the problem when ventilation is not sufficient and can serve as the distribution channel for other contaminants. Proper design and maintenance for the correct amount of ventilation and proper cleaning of the HVAC systems are of primary importance in prevention of IAQ problems.

HVAC equipment, including the mechanical conditioning components, and the HVAC controls, can have various effects on indoor air quality. In its most basic form, the HVAC equipment must serve the purpose of providing conditioned air to maintain comfortable temperature and humidity in the occupied space. In order to perform this service, the air must be heated or cooled, dehumidified or humidified, delivered to the occupied zones and, after being “used” by the occupants, removed for discharge outside or reconditioning for re-use.

Most large facilities use some form of centralized control system in order to maintain the proper settings for HVAC systems. Centralized controls can also provide an input area for nearly all the measurements needed to test the quality of the air in addition to its temperature, humidity, and movement.

Whether through centralized controls or local thermostats and humidistats, the comfort conditioning of a building is the first “air quality” factor most people will notice. If a space is too cool, warm, humid, or dry, occupants will complain about the conditions.

HVAC systems may also now include some form of heat recovery. Heat recovery systems reduce operating cost by using some of the heating or cooling energy in the air being exhausted to condition the intake air. Some heat recovery systems can add another component to the supply air system which has the potential to reintroduce returned contaminants.

Still, even if it is internally isolated from intake air, the exhausted air from any building has the potential to be re-entrained by the equipment. Re-entrained exhaust air uses non-obvious routes to return to the facility. In cooler seasons, air exhausted from lower floor mechanical systems can rise smoothly up the side of a building and be captured by rooftop intakes. Self-contained rooftop units usually have the exhaust air grill immediately adjacent to the intake.



The exhausted air itself serves a purpose in helping to manage air quality. If an insufficient amount of air is exhausted from the building, inside pressure will be greater than outside, which can prevent proper amounts of air from being taken in. If too much air is exhausted, building air pressure may be lower than outside air and force air infiltration through unplanned openings. Section 3.2.7 covers the overall issue of ventilation in greater detail.

Point, or local, exhausts can cause worse problems if they contain specific contaminants which are odorous or noxious to the people in the building. Most critical applications, such as discharges from laboratories, printing shops, and industrial processes have exhaust systems properly designed to prevent re-entrainment into other parts of the building. However, areas deemed less critical, like toilet exhausts and local kitchen or cooking area exhausts discharge air with little concern for the location of air intakes other than that dictated by local or national building codes.

The exhaust does not have to be close to the intake in order for a problem situation to arise. Quickly growing industrial complexes are notorious for exhausted airstreams from one company causing problems at the intake of another located downwind from the first. Problems usually arise due to a unique process or odor from one building. Since the EPA thoroughly regulates emissions of toxic chemicals and individual companies themselves control other emissions, odor problems of this sort typically lead to perceptions of IAQ problems.

Specific issues with IAQ are characteristic of certain types of HVAC systems. All of these systems have been covered in other manuals from the viewpoint of how they work to condition the air. The following sections discuss how some of the most used types of systems contribute to common IAQ problems.

3.2.1 Multi-zone (MZ) Systems

Multi-zone (MZ) systems, systems which deliver air to multiple locations in one building, have a number of inherent problems with respect to IAQ management. One of the most prevalent problems with MZ systems actually occurs after the building has been in operation for some time.

A newly installed and commissioned MZ system in a new building is very likely to meet most IAQ criteria without much difficulty. MZ systems are usually designed originally to supply and extract air from multiple locations of the same type of operation. That

is, all of the zones on one MZ system will be offices or similar purpose classrooms. After the building has been in operation for some time and undergoes modification in purpose, the uses for some of the spaces under one MZ unit are likely to change enough to cause cross-contamination problems. One cross-contamination issue which arises regularly is the addition of an eating or food preparation area as one of the zones.

Most kitchen or food HVAC regulations concentrate on the issue of carcinogenic components of fried foods. Local food preparation areas or small break areas, often with microwave ovens or other food heating appliances, are typically not regulated. The odors from food preparation, coffee services, cleaning products used in the food areas, and stain removal products (some with noxious odors) cause perceptions of more serious IAQ problem. Odors from food consumed by others almost always cause complaints of poor ventilation. If food odors are not removed overnight, occupants entering a building the following morning will notice them even more quickly as they encounter the difference from the fresh outside air. MZ systems must be managed with more attention to the various activities of the occupants and the usage of the zoned area.

Another issue with MZ systems arises when the comfort needs of the zones are widely varied. This results in an imbalance in air delivery and causes problems with outside air ventilation rate in the zone, or zones, with the least need for comfort control. This problem also occurs with VAV systems. (See Section 3.2.3.)

3.2.2 Constant Volume (CV) Systems

CV systems deliver air to the occupied spaces in several different ways. One is by mixing heated and cooled air at the central system in quantities required by a single space in the building. Another is to mix air at the central system and provide separate ducting to deliver conditioned air to each of several spaces. (See Section 3.2.1). The third is to supply both heated and cooled air to separate ducts, meeting the extreme requirement for each at the central system, and mix the two airstreams at the terminal area. CV systems have the same problems as MZ systems as well as the problems listed below.

Thermal comfort can also be an IAQ problem. In CV systems, when one zone is at an extreme in terms of temperature needs, the other zones can suffer from comfort problems as the mixing boxes try to close off either the hot deck or the cold deck source. Local cycling occurs and leads to more severe issues of

comfort. We usually associate air which is too warm with a lower degree of air quality. However, air which is too cold or produces intermittent drafts can actually cause more serious problems if the levels of other contaminants remain the same. Too cool or drafty spaces create a perception of dampness as extreme as warm humid spaces.

3.2.3 Variable Air Volume (VAV) Systems

In a VAV system the air is delivered at a constant temperature, usually 55°F (12.8°C), and the volume of air delivered is modulated in order to maintain desired conditions. A sensor located in the occupied space sends a signal to a controller to set the air volume.

If the space conditions meet the set point of the controller, the air volume can be sufficiently limited to reduce the outside air quantity below the recommended level. Human biological effluents, including products of respiration (such as carbon dioxide), can build up to excess levels during periods of low demand for comfort conditioning.

Supply fan and return fan air movement is controlled by inputs from pressure sensors in the ductwork. As volume requirements change, the sensors indicate varying pressures and change the corresponding fan speed to return to proper pressure. If building pressure is in the range of 0.025 to 0.05 in. wg, outside contaminants are not likely to infiltrate the building in air-streams attempting to balance the pressure with inward flow.

3.2.4 Heat Pump Systems

Heat pumps in commercial applications are sometimes located in plenum spaces where it may be difficult to introduce sufficient outside air for proper ventilation. Some heat pump applications have minimum outside air always ducted direct to the area of the heat pump within the plenum.

Outside air has the potential to cause problems when introduced into the occupied space in ceiling plenums before it is treated in any way except filtering. High moisture levels in the intake air cause fungal growth in the plenum area which can be nearly impossible to catch and resolve before becoming a serious problem. Even if the outside air is at lower RH than will typically cause problems, the humidity in the occupied space can add to the total moisture level in “dropped-ceiling” plenum spaces in sufficient amounts to create microbial amplification areas.

The cleaning of any HVAC system component located in ceiling plenums is often delayed longer than other cleaning requirements. The added cost for ceiling removal, relocation of ladders and scaffolding, and the difficulty of working above desks and other office furnishings creates an additional burden for the building owner.

As with some other HVAC equipment, heat pumps mounted in obscure locations have even greater problems when their location is not taken into account during remodeling of the workplace. New walls which meet dropped ceilings below heat pumps make it impossible to properly clean and service the equipment. Condensate drain pans, and the drains themselves, can result in the same problems with hidden locations. Dirty pans and clogged drains still must be cleaned even if the equipment is difficult to locate and service.

3.2.5 Unit Ventilator (UV) Systems

Schools, hotels, and other institutional types of buildings use individual unit ventilator systems to maintain the room-by-room environments. The most evident problem with this arrangement, especially in buildings where operating and maintenance budgets are already too low, is a lack of attention to regular service on the equipment. Improper, or inadequate, service contributes to IAQ problems with all types of HVAC equipment. Since each room in a school is dependent on one unit for comfort and quality conditioning, proper service is crucial.

Freezing coils can be a problem with UV systems that cannot handle outside air design conditions. One solution to the problem has been to seal the outside air intake, often in a permanent fashion. This causes an immediate and critical increase in the carbon dioxide levels which can reach concentrations sufficient to cause drowsiness and lack of attention. This may be the most prevalent cause of indoor air problems in schools today.

Cooling coils and condensate drain pans are subject to the same problems of design errors and lack of maintenance. Pans often drain into the room space due to clogged drains from sludge in the pan or from outside work which has sealed the drain outlet.

3.2.6 Air Filters

Removal of particulates from the supply airstream to an occupied space and from the return air is as important to overall air quality as removal of chemical contaminants. Filtration of these particulates is the common method of removal. More complex systems are



used when toxic contaminants are in the air or when chemical washing is necessary to meet industrial regulations.

Air filters for the removal of particulates from the air in HVAC systems must remove a wide range of particle sizes and types. The intake air (fresh outside air from the atmosphere) contains combustion particulates, dust (soil dust as well as particulates from other sources), plant and animal matter in various states of decay, mineral fibers, and possibly live animal matter such as pollen, mold spores, and bacteria. Table 3-1 shows the range of particulates which filters must remove in order to pass clean air.

According to ASHRAE, it is impossible to design a single filter which can remove all of these particulate contaminants since the size of the particulates varies over such a wide range and the quantity of particles is similarly varied from one size range to another.. They define particles of 2.5 μ (micro-meters) or smaller as fine particles and particles greater than 2.5 μ in size as coarse particles. Particles of 5 μ or smaller are respirable by humans while particles below 2.5 μ are not only respirable but will become attached to the surfaces in the lung.

Respirability, filtering, and particle attachment to surfaces are also affected by the density of the particles and by their shape. Low density particles of larger sizes may also be respirable. Particles in fiber forms are more likely to attach and penetrate the critical areas of human lung tissue.

The particles originate from different sources and act in different ways depending on their size. Fine particles originate from condensation or as original combustion products. Coarse particles come from physical actions such as abrasion, erosion, and decay and may be removed from the airstream by gravity. Fine particles are not as likely to settle out of the airstream

due to gravity and are more likely to create soiling on vertical surfaces or on ceiling surfaces.

The type of filtration used in any application is dependent on a few major factors.

- a. Particle density in the air and particle size.
- b. Types of particles encountered (i.e., toxicity, fibrous nature, odors, and other factors).
- c. Allowable filter resistance in the HVAC system.
- d. Cost effectiveness of the filter in a given application.

Expected particle density, size, and shape are functions of the building location, the surrounding ambient air, and the particulates which must be removed from the return airstream. Consideration should also be given the nature of duct lining and its age and state of deterioration to select a change in filtration products for an existing installation. As the function of a workspace changes, the needs for filtration of the return airstream may also change due to different particles in the occupied space.

Particle types are usually a function of the building operation. The work carried out in the facility is more likely to create particles of a widely varied nature than encountered in the ambient air. Particle types are also dependent on duct linings, ceiling tile deterioration, and carpet and furnishing wear. Particles from the last two items (carpets and furnishings) are likely to be in a much larger size range than are respirable. However, even though they may not be respirable particles, carpet, and fabric particles can be captured by the HVAC return airstream and become components of a microbial breeding ground or amplification site in the system.

Particles	Size Range
Combustion products, radon particles	up to 0.01 μm
Cigarette smoke, cooking byproducts	up to 0.1 μm
Airborne dust	0.1 to 10 μm
Soil, pollens, animal antigens, other allergens	10 to 100 μm & larger

Source: ASHRAE HVAC Systems & Equipment

Table 3-1 Atmospheric Particles In Intake Air

Allowable filter resistance is based on the ability of the HVAC system to move air through the complete circuit. Added filter resistance, such as systems with high-efficiency filters, will use additional horsepower to move air through the system. This increase in power will lead to an added cost of operation. Note that most filter media are rated for resistance or particle arrestance at some time after installation. A new filter will typically not perform as efficiently as a filter which has already trapped some quantity of particulates.

Cost effectiveness of a given filter media and application is a complex combination of:

- a. Cleanliness requirements in the occupied space.
- b. The need to remove contaminants and particles which cause odors.
- c. The return on the investment in filtering to accomplish these tasks.

Higher efficiency filters will cost more initially and will cost more to operate due to higher air flow resistance. Specialized filter media, such as roll and electronic filters, can offer effective solutions at a lower total operating cost. However, the lower operating cost may be offset by higher initial equipment and installation costs.

Based upon the selected filter media, filters remove particles from the air passing through them by:

Straining – Straining simply uses an opening smaller than the particle to be removed. The opening may be part of a hard (*i.e.* non-porous) surface or it may be the upstream side of a filter made of fibrous materials. Lint, dust, dirt, and animal hair are the type of airborne contaminants which are removed by a straining effect.

Direct Interception – Particles smaller than those intercepted by straining can become attached to the same filter media simply by traveling close enough to the edge of the opening to become lodged on the filter. Direct interception effectiveness is not based on air velocities in the HVAC system. Increasing air velocities however, can affect the amount of particles retained by the filter after initial contact.

Inertial Deposition – At higher air velocities some of the larger, or more dense, particles are unable to follow the air stream as it changes direction on its path through the filter. These particles will become

attached to the filter media in much the same manner as direct interception except for the difference in air speed. Oil, or some other fluid, aids in attaching and retaining these larger particles.

Diffusion – Diffusion is based on natural particle movements as distinguished from the airstream changes in direction. Small particles have sufficient Brownian movement to impact the filter media even though their initial path through the filter did not lead to impact. As the filter holds more particles, the diffusion process becomes more efficient due to the increased potential impact area. Diffusion is more effective with both smaller particles and lower air velocities.

Electrostatic Force – Electrostatic filtering is based on the attraction between two objects possessing opposite electrical charges. As dust passes through one component of an electrostatic filter it is charged to one polarity. The filtering element has the opposite charge and attracts the dust to the filter media.

ASHRAE Standard 52 defines four methods for testing air filters for different applications:

Arrestance Testing – Arrestance testing uses a standard dust made of synthetic material and consisting of varied size particles. The test results are stated in the percentage of the dust fed into the test which was captured by the filter. Effectively, the arrestance test is used to determine the ability of the filtering device to remove the larger of the typical airborne particulates found in the ambient atmosphere.

Dust Spot Efficiency – The dust spot test consists of standard atmospheric dust particles fed into the filter media and a measurement of the discoloration on paper targets placed downstream of the filter. Most often used for higher efficiency filters, this test indicates the relative value of a filter in preventing smaller particle, atmospheric dust from causing discoloration on interior fabrics, wall surfaces, ceiling tiles, and other surfaces to which the dust may become attached.

Fractional Efficiency – Fractional efficiency is measured using a fixed size of particle and testing for the penetration of particles through the filter. The DOP test uses a standard particle of dioctyl-phthalate for tests typically conducted for research purposes. Fractional efficiency tests are costly to perform.

Particle Size Efficiency – The particle size efficiency test most closely gauges the effectiveness of the filter in meeting the needs for intake air. It uses standard, variably sized atmospheric particles to test for



the efficiency of the filter. This test is used by industry to measure and be able to present an “efficiency” figure which is more understandable to building staff and private users.

The DOP test is also used to determine penetration rates for high-efficiency-particulate-air (HEPA) filters and to locate any specific leakage points for filters in continuing use.

All filters consist of some manner of attracting, collecting, and retaining the elements they are intending to filter from the airstream. There are several methods by which various filters accomplish these tasks. Except for the electrostatic method of attraction and retention, the means by which a filter removes particles from the air is not necessarily evident from the appearance of the filter.

Most filter media is fibrous material. The filtering fibers are woven, or matted, together more tightly to achieve higher degrees of filtering. Some filters have chemicals added to enhance the attachment and retention of particulates. In fiber filtering media the pressure drop across the filter increases as the filter becomes more clogged with dust. At the same time, the filtering efficiency increases and the energy, and therefore cost, to move the same amount of air through the filter increases. As the filter becomes overloaded, the captured material will begin to be pulled off by the airstream and the filter’s effective efficiency drops.

Normal fibrous filters of the removable type are often used to remove larger particles in front of more efficient, or HEPA filters. The bulk work is done by the less expensive, replaceable media leaving the high efficiency filter to remove smaller particulates.

Fibrous filters come in varied construction types to meet a wide range of needs. Roll filters can accommodate large system needs by replacing part or all of the filter face within the HVAC system on a regular basis. One way to improve roll filter effectiveness is to control the roll advancement based on pressure drop, rather than time. The sensors must be installed at a point not affected by changes due to damper positions or other outside influence. An alternative to using pressure drop to manage filter advancement is to use light transmission. New filter media will not be as efficient as media already partially clogged with particulates. The new media, however, will also be more energy efficient and will tend to lose less captured dust and dirt to the airstream.

Panel filters, the pleated bag, and plastic screen types are typically fibrous material but are also constructed of expanded metal screens with more open space to reduce pressure drop. A viscous oil or adhesive may be added to fibrous filters to increase attachment and retention of small and large particles.

ASHRAE groups fibrous filters into four categories:

Group 1 – Panel filters of spun glass or open cell foam and some screens. The fibers are either natural or man-made. Group 1 filters have arrestance ratings from 50 to 90%.

Group 2 – Pleated (to extend the surface area in the same duct cross-sectional area) made of finer, and more closely woven, materials than Group 1. Group 2 filters begin at 80% arrestance and range up to a 30% rating in the ASHRAE atmospheric dust spot efficiency test.

Group 3 – More extended surface filtering elements of fine glass or man-made fibers. Some are made from wet-laid fiber matting. These filters begin at 30% ratings for the atmospheric dust spot test up to 98% on the same test and up to 80% on the DOP test.

Group 4 – Extended area pleated filters of the HEPA type, constructed of fine wet-laid filter papers. Effectiveness for filters in this group ranges from 95% DOP efficiency to 99.97% for HEPA filters and 99.999% ULPA filters.

Electronic filters are another category completely. High voltages on the filter plates create a charge on the particles which are then attracted to the collection area. Electrostatic filters are typically renewable and work best at air flow velocities from 150 to 350 feet per minute. The ozone emitted by high voltage devices is not typically a problem with well designed electrostatic filters. Current products produce ozone at levels less than 1/3 that allowable for long term exposure as specified by OSHA.

Filters should be selected based on:

- a. Efficiency of particulate removal.
- b. Quantity and type of particulates to be collected.
- c. Pressure drop.
- d. Available space for the filter element(s) in width, height, and thickness.

- e. Cost of maintenance.
- f. Initial investment.

3.2.7 Ventilation Issues

The proper amount of outside air ventilation is defined by ASHRAE Standard 62–1989 and by local codes. The methods to determine proper ventilation are discussed in Chapter 7. However, there are other problems with ventilation as a control method for IAQ beyond determination of the amount of outside air flow.

3.2.8 Stack Effect

Stack effect is the result of air rising from the lower floors to the upper floors of a building whether caused by temperature or pressure differentials between the two extremes. Stack effect can impact air quality in several ways.

The first effect noticed in many facilities is the difference in temperature, or comfort level, from lower floors to upper floors. Warm air rises through the building when stairwells, elevator shafts, and service cores are not properly closed off or are operated at the wrong pressures with respect to the surrounding areas.

In addition to the direct temperature difference, the air velocity, in moving up these channels, can become excessive to the point of draftiness. Air movement vertically in an elevator or service shaft can also become a noise issue.

Stack effects in high-rise facilities can also cause pressure differences. If the upper floor occupied spaces become over pressurized, with respect to lower floors or the proper balance point for the HVAC system, the systems cannot deliver the correct amount of air (including outside air for ventilation) to the space. This further compounds the problem of discomfort in the space by adding the issues of CO₂ increase and complaints due to odors.

Solutions to the problems of stack effect can include professional balancing, tighter control of supply-return differential pressures, addition of closures, and addition of balancing dampers. A proactive building owner can monitor temperatures at various levels in the building and track comfort complaints to determine if stack effects are present in the building.

3.3 MICROBIAL CONTAMINATION

If microbial contamination is found in some area of the HVAC system, it is important to identify the root cause of the problem. Fungi breed in the damp, dark areas of systems and their spores may be carried throughout a facility by ventilation and air distribution airstreams.

In addition to fungal contamination, there are other biological contaminants found in HVAC systems and in the spaces the HVAC systems serve. Bacteria of several types are common. Legionella is one of these bacteria which may originate and grow in certain building equipment. The primary problem areas for legionella growth are cooling towers, drains, and large bodies of standing water.

Mites, excreta from mites and insects, dander from cats, and pollen are other forms of biological contamination which may be found in the air. From the list it may be obvious that cleaning plays a major part in remediation of these allergens or irritants. Cleaning before the biological growth becomes excessive or before it begins is the best solution.

Endotoxins, which are the shed outer elements of decaying bacteria, are distributed by the ventilation air stream, and are suspected of being the agent causing some sick building syndrome complaints. While the evidence is unclear as to the role played by endotoxins in human illness, they should be reduced or eliminated to mitigate air quality and general indoor environmental issues. Endotoxin can be reduced by cleaning before bacterial problems begin. Check the ductwork often (quarterly in any place with humidity levels regularly over 70%) to reduce the risk of unnoticed growth.

Infections, allergic reactions and symptoms, chemical toxicity reactions, and upper respiratory irritations are common results of biological contaminants in the indoor environment. Headaches, dizziness, and nausea may also appear in some individuals.

Mold will grow in areas where the environment supports the spores with moisture and nutrition. Amplification areas include the immediate vicinity of cooling coils and drain pans, ductwork downstream from these components especially if the air flow rate is sufficient to carry moisture from the coil, and equipment rooms and mechanical rooms which are not kept dry. The nutrients which mold requires to grow are typically found in dust which includes human skin flakes and other dead or decaying biological materials.

The humidity level to support mold growth is accepted as 70% or higher. When the ASHRAE Standard



62–1989, “Ventilation For Acceptable Indoor Air Quality”, was released, there was considerable argument over one section which suggests that the relative humidity level in an HVAC system never exceed 60%. This is nearly impossible to achieve in systems where condensation is used to reduce moisture, or in systems requiring spray or steam humidification. These components must be inspected for microbial growth more often and cleaned immediately if growth is present.

Mold also requires the correct temperature to grow. The range is, however, wider than that found in most occupied buildings. Mold will grow in temperatures from 40 to 100°F (4.4 to 37.8°C).

The EPA and North American Insulation Manufacturers Association (NAIMA) recommend that porous material which has been contaminated be removed rather than cleaned. There is significant evidence that fungal spores are released into the airstream during cleaning of any porous surface, during construction and demolition, and during maintenance on contaminated equipment. Stained materials must be removed as the first step to help avoid this problem.

In the process of reviewing a facility, investigate all sites which may be potential amplification areas. Visual inspection is adequate unless some problem is suspected from prior experience.

Pay careful attention to carpets, especially in areas where water or other liquids may be spilled (*e.g.* near coffee machines, water coolers, and soft drink dispensers). Wall board or other covering which shows evidence of mold growth should be noted on the visual inspection. Some furnishings and panels may also be growth or amplification sites for biologicals.

Odors are also a clue to some mold growth. Musty or mildew-like odors are well known to anyone who has experienced them. Mold odors also may be long lasting and cause a sensory reaction long after you have left the infected area. This may be due to mold spores becoming attached to the cilia in the respiratory system.

If you need to test, the collection of samples and growth culturing should be handled by a qualified laboratory. Since the levels of fungal spores changes from one location to another over time, it is difficult to determine a baseline concentration level against which to define limits. Generally, tests for “viable mold spores” (those which exhibit growth capabilities) are compared with the following guidelines.

Fungal count – 50% or less than the outdoor reference test.

Fungal count – less than 200 colony forming units per cubic meter (cfu/m³).

Fungal count – if greater than 500 cfu/m³ in winter, ventilation is insufficient.

Fungal species – not significantly different from the outdoor species.

Fungal species – unusual spores or those known to cause illness should be separately investigated.

3.4 CHEMICAL CONTAMINANTS

Chemical contaminants are often the most difficult indoor air pollutants to identify in terms of source and effect. Combinations of chemicals can have serious medical results but so many combinations are possible that little is understood about the origins or mechanisms of the illnesses they can cause.

Chemical management is one of the most important tasks for the proactive building owner, after proper maintenance and management of the HVAC systems. Chemical problems fall into several different categories with the most prevalent being volatile organic compounds (VOC). VOC's emit vapors which are objectionable or toxic to the occupants of a building. VOC's come from numerous sources in the building and in some cases are entrained into the building air stream via the intake air grilles.

3.4.1 Volatile Organic Compounds (VOC)

Volatile organic compounds are carbon compounds consisting of various combinations of hydrogen, oxygen, and carbon with less significant additional elements. Little is known about the symptoms of overexposure to VOC's but they are suspected of causing serious health effects. Combination, or synergistic effects are even less understood due to the large number of chemical reactions possible in the air and possible after being captured by the human body.

Tobacco smoke is one source of VOC's and particulates. Exhaled tobacco smoke, in combination with side-stream smoke from burning tobacco is referred to as environmental tobacco smoke (ETS).

Building and decorating materials, cleaning products, and pesticides are currently the most significant con-

tributors to VOC emissions in residential, commercial, and institutional buildings.

3.4.2 Fossil Fuel Emissions

Fossil fuels contribute quantities of VOC's in proportion to the effective evaporative surface area of open containers. VOC's also get into the air stream as combinations of compounds in the exhaust from internal combustion engines or fuel-fired heating systems. Fuels contribute benzene, toluene, lead (much reduced now) alkanes, butane, and more complex compounds of these in addition to lesser amounts of many other VOC's to the air. Although not as volatile as the fuels themselves, the oils, and lubricants used in engines can emit similar VOC's in smaller quantities.

Headaches, nausea, vomiting, loss of coordination, can all be caused by VOC exposure. Longer term effects such as loss of ability to concentrate and nervous system disorders may also result from overexposure to VOC's from fuels. Odor sensitivity thresholds for some of these VOC's may provide an indication of increasing exposure. However, the olfactory sense quickly acclimates to new VOC odors which can lead to occupants ignoring a potentially dangerous contaminant situation in the occupied space.

Vehicle exhaust can be entrained from attached garages, air intakes located near shipping and receiving docks, and from areas with high traffic levels. As taller buildings are built, their shorter neighbors may get below average wind to remove road generated contaminants thus drawing in air at a higher contamination level where vehicle exhaust is a problem.

Source control of VOC's from fuel exhaust and evaporation consists of two primary methods. The first is to remove any possible evaporation routes to indoor spaces. Gasoline, kerosene, propane, and the oils used in combustion engines should be stored in locations outside of occupied spaces. The storage facilities for fossil fuels and lubricants should be ventilated to prevent buildup of fuel vapors. Fuel containers must meet federal standards and should be closed when not in use.

Residential problems with fuel emissions result from attached garages where vehicles warm up in an enclosed space and from open fuel containers. Home heating systems and cooking appliances also can contribute to VOC's from gas or oil. Incomplete combustion in heating systems may be one of the leading contributors to residential air problems. Incomplete gas

combustion also leads to high levels of CO which can be measured as an indicator of combustion problems.

CO detectors are becoming accepted practice as well as law in many communities. CO detection systems are called for where combustion products may be released indoors. Particular areas of concern are residential space heaters and wood stoves.

The second basic method to reduce combustion products is to move air intakes away from vehicle exhaust areas or change the location for truck and car stops. One specific case where this procedure can benefit buildings is in the emergency ambulance areas of hospitals and other medical centers. Ambulances parked in hospital emergency drives are left running. Exhaust contaminants may be entrained in the building air via the large emergency doors and nearby building air intakes. Some hospitals have initiated policies to force ambulance drivers to turn off their engines while parked at emergency entrances. Other examples of this problem are loading docks, drive-in banks, or retail stores, and bus stops or loading areas on city streets.

3.4.3 Cleaning Products

Cleaning products are the source for some of the chemical contaminants found in occupied spaces. Part of the reason for the problem is lack of control over how everyday cleaning products are stored and used. As noted elsewhere, many large organizations now use systems for controlling the dilution of cleaning products to prevent the use of higher-than-acceptable concentrations. Households and industrial users store cleaning products like ammonia and bleach, which form highly toxic chlorine gas if combined, in the same cabinets. In homes, these two items are typically stored next to each other under the kitchen sink.

Commercial cleaning, of clothing and furniture, uses products which emit toluene, 1,1,1 trichloroethane, and tetrachloroethane (now in very limited use). These VOC's are very toxic to humans. Automobile cleaning involves some of the same substances and adds to the respirable VOC's in cars which may be closed tightly for long trips in any season.

Household or industrial cleaners are often treated with a scenting agent to counter the noxious odor. Often these additives are as likely to emit VOC's as the original chemical, but produce favorable odors which mask the original chemical odor.

Cleaning solvents and other cleaning agents have the potential to be more dangerous than other types of



COC's because we have been acclimated to the odors since childhood, and do not identify them as problems.

The industrial solvent, 1,1,1 trichloroethane causes tingling of the facial muscles, tongue, and lips. Exposures can be cumulative in industrial solvents. Symptoms may become worse as the work week progresses and diminish when the affected person is away from the workplace.

To reduce the possibility of overexposure to VOC's from cleaning products, never use them without the proper ventilation or protective equipment. Once cleaning is complete, problems can be reduced by introducing large amounts of clean, outside ventilation air. Dry cleaning which has just returned from the cleaners in sealed plastic bags can pose a severe toluene problem. Remove the plastic covering before bringing the cleaned items into the home and hang freshly dry-cleaned items in a closet other than those in sleeping rooms.

In a commercial setting, allow a weekend of un-occupied time after using aromatic hydrocarbons to clean carpeting, furnishings or panels. Only apply spot or stain removers when spaces are unoccupied. Some of the newer industrial stain removers are less toxic, but contain some sulfur compounds which are noxious enough to cause occupants to have perceptions of poor air quality.

As discussed in Chapter 10, be certain any cleaning service, whether inside staff or contractor-based, has been properly trained to handle the chemicals they use.

3.4.4 Pesticides

Exposure to pesticides from occupancy too soon after treatment or improper application pose a health risk. Pesticides are designed to destroy living pests or their ability to reproduce. Pesticides generally fall into six different categories. Organophosphates, carbamates, organochlorines, anticoagulants, substituted phenols, and miscellaneous chemical compounds. In addition, the chemicals used for herbicides, dipyrityls, fall into the same contaminant categories as pesticides. Ask any pest control service which type of products are being applied and keep the information on the product along with other IAQ documentation.

Pesticides can be applied either inside or outside a building and may cause IAQ problems from either location. Occupants track residue chemicals from

outside applications into the facility where the chemicals are trapped in carpeting and furnishings. Home-owners and commercial building managers often treat pesticides as an everyday chemical, giving no thought to contamination.

Many of the methods used for application of pesticides do not result in air contaminants. The most prevalent air quality issues come as a result of spray applications around the perimeter of buildings, either inside or outside of the facility.

Symptoms of overexposure to pesticides are wide ranged and can be severe, including loss of mental function, coma, and death. Consult the manufacturer's warning labels for all pesticides and refer to the Material Safety Data Sheets (MSDS) for other details.

One of the most severe problems with pesticides occurs due to application of the chemical product without sufficient dilution. Schools are particularly susceptible to problems from excessive exposure because small children are more likely to have severe symptoms from a given exposure level of pesticide VOC's than a large adult.

Pesticide releases must be carefully controlled. After-the-fact dilution with outside air may reduce the immediate concentration in the air, but is unlikely to eliminate the source of the problem. Select the best application method for each pesticide to further reduce air contamination. Hard surface application will cause more immediate evaporation while porous surfaces will absorb at a higher rate and release the VOC's more slowly. Pesticides are usually sprayed for wider effective range and to destroy a wider range of insects. Non-spray methods like pest strips or traps reduce air contamination.

Liquid nitrogen is one of the newest pest-killing chemicals. The specialist sprays liquid nitrogen into a wall cavity or other opening. The temperature drop can kill most common insect pests. Since the liquid immediately vaporizes on release to atmospheric pressure, there is not sufficient mass to affect water pipes or other potentially susceptible components in the wall. The advantage is that liquid nitrogen becomes gaseous nitrogen almost immediately and, since nitrogen makes up 78% of our normal outside air, is completely non-threatening to the overall air quality.

Pesticides should be applied when facilities are unoccupied. If "bug bombs" are used in a home, the family (and pets) should plan to be away for at least 24 to 48 hours. Fully ventilate the home or commercial

building before re-occupancy. Wash down all surfaces in food and restroom areas before use after pesticide application.

Some state and local regulations require notification of all occupants at least 24 hours in advance of the use of pesticides. People, primarily working occu-

pants, may be able to plan to work in a different area while the pesticide is being applied.

Destroy all old pesticides or any pesticides for which you do not have current MSDS and intact labels. Only allow trained staff to use pesticides. Contact your state EPA if you have any questions regarding disposal of pesticides.



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CHAPTER 4

SOURCES OF INDOOR AIR QUALITY PROBLEMS

4.1 EXTERNAL FACTORS AND CONDITIONS

Contaminants and pollutants can come from sources outside the building. The most prevalent of these pollutants is vehicle exhaust in areas where building intakes can entrain contaminated air near roads and highways. Other external contaminant factors come from industrial sources often in the form of vapors and particulates which originate in heavy manufacturing and chemical processing operations.

Regardless of the source of exhaust (whether from vehicles or factories) the initial step in any solution is to be proactive in locating air intakes. HVAC ventilation intake grilles should be moved to take advantage of prevailing winds and to be as far from the exhaust sources as possible to prevent re-entrainment of exhausted air. Loading docks, hospital emergency rooms and trauma centers, buildings which border heavily traveled highways, and buildings with air intakes located in alleys are all candidates for problems due to entrainment of vehicle exhaust. In an industrial park all building operators should be aware of what potential contaminants can come from a neighboring building.

Buildings near large patches of vegetation (*i.e.* primarily open fields and grasslands) should have effective particulate filtration to reduce the entrainment of allergens such as pollen and spores. Sensitive people may develop allergic reaction symptoms at very low levels of pollen, dust, and fungal spores. These symptoms, when they first occur inside, are often assumed to be due to inherent problems with the indoor air.

External odors are another cause of possible indoor air complaints. Air intakes in alleys may bring in odors from refuse and dumpsters. Intakes in confined spaces can re-entrain the building's own exhaust which causes odors. Odors from adjacent buildings can also be a problem. Some of these, such as cooking odors, are readily explained. Others may cause serious concern for the occupants if they do not know the origin or nature of the odor.

Radon originates as a soil gas which can get into the lower portions of buildings through cracks in foundations. Radon is fully covered in several EPA publications available through the Government Printing Office (GPO).

Microbial contaminants can come from standing water and moisture in any outside location. If the building air system has the potential to capture these con-

taminants, they can be carried into the air distribution system and distributed throughout the facility.

Many external pollutants will be sufficiently diluted in outside air prior to the possibility of capture in a building's intake air system. However, in locations where the buildings must be near the source of pollution it may be impossible to completely block the intake of contaminants.

4.2 BUILDING MATERIALS AND FURNISHINGS

Building materials, such as paint, glues, insulation, and other products which are used for interior decoration, emit VOC's during installation and afterwards. Products applied in a liquid state, such as paints, wall and floor covering adhesives, wood finishes and finish removers, waxes and polishes, and other glues emit higher levels of VOC's when first used. Usually, the emission rates drop rapidly as the product dries or cures. At the same time, some of the VOC's emitted by these products are retained by the body and may cause long term cumulative effects.

Typical VOC's emitted by paints, adhesives, wood treatments, and similar common products are amyl and ethyl alcohols, formaldehyde, benzene, glycerol, hydrogen sulfide, methylene chloride, toluene, phenols, and xylenes. Additionally, these finishing materials may also emit some of the same gasses as the VOC's from fuels noted earlier.

The routes these contaminants use to enter the breathing air space are so obvious sometimes that we do not even think to prevent them. Painting in an occupied building or not allowing sufficient time after painting before re-occupancy is one of the largest problems in commercial facilities. Paint fumes travel throughout occupied commercial, industrial, and institutional facilities when painting is done during the normal ventilation and recirculation cycle. Most retailers learned to keep paint fumes out of the store space due to the high level of objection of customers.

Polishing and waxing floors or furniture adds a wide range of contaminants such as turpentine from some products. Residential products have somewhat lower emission rates but are used with less care for the air quality. The additives used in residential wax and polish products can add additional VOC's or other contaminants to the air.

Glues, adhesives, related artwork, and hobby products can emit VOC's during application and until they are cured or dried. While computers have taken over



much of the work in creating layouts, posters, and general artwork for most companies, many art departments still use spray and brush-applied adhesives. Some adhesives and sealants, such as epoxy or polyester resins, cyanoacrylates, and silicones, cause noticeable odors for hours even after the cure time has passed. Emissions from uncured silicone caulk is also highly noxious to humans. Though hobby uses contribute small amounts of VOC's in the home, some of them may be highly toxic.

Control of decorating and building product VOC's leads to much lower total VOC (TVOC) levels in any type of building. Ventilation for dilution (see Chapter 7) of the contaminant level can reduce, but not eliminate, the problem. Most HVAC systems cannot provide sufficient outside air to fully dilute VOC contamination below concern levels and below odor thresholds. Complete ventilation with 100% outside air during application or use of decorating products helps to reduce the problem.

With some construction, artwork, and hobby products, complete ventilation is a must. Cyanoacrylate adhesives (CA) emissions are highly toxic. They emit cyanides and compounds of cyanides from small applications of CA. Working in tight quarters means breathing the emissions close to the source and at high concentrations. Gluing only a few parts with CA can cause noticeable dizziness and lightheadedness. Long term exposure leads to loss of ability to concentrate.

Store artwork, hobby products, and other adhesives, waxes, and polishes with the same care and concern as for the storage of fuels. Ensure glue containers are tightly sealed when not in use. Prevent the highly toxic emissions from CA and resin products by capping them between applications. Do not mix adhesives without thorough knowledge of the results.

Emissions of VOC's from building products drops quickly with time. According to a study by Dr. Thad Godish, *Indoor Air Pollution Control*, the TVOC emissions from vinyl caulk decrease to less than 10% of the initially applied value in 10 hours or less. Other studies show emissions decrease as a function of time, humidity, and temperature.

Generally accepted practice for control over this area of VOC emissions is by ventilation during use or application as well as control over where these products are used.

4.3 MECHANICAL SYSTEMS

Building mechanical systems can cause, or amplify, IAQ problems in many ways. This section will not discuss the basics of how mechanical systems operate, but will cover several of the common types of IAQ problems encountered in facilities where the equipment is not operating properly.

In all cases, before a determination of the problem can be attempted, you should investigate the building's equipment with respect to how it is designed to operate and its current operating condition. After comparing this information with the baseline information available on building ventilation (from the forms in Appendix A) you can develop a hypothesis as to how the problem arose.

4.3.1 Negative Building Pressure

The makeup air brought in to a building to balance the exhaust air must bring the facility to a positive pressure. If the building is negatively pressurized, the additional balancing air must come into the space from unplanned entryways. These air routes nearly always contribute to foreign contaminants. Negative building pressure contributes to the entry of ground level pollutants such as radon, molds, and products of decaying vegetation. Odors and uncomfortable temperature or humidity conditions in the occupied space are more difficult to control if air infiltrates the building from unplanned openings. The fact that the infiltration air is not filtered contributes even further to the entrainment of contaminants. Building pressurization should be in the range of 0.025 to 0.05 in. wg for proper pressurization.

4.3.2 Intake Damper Problems

Outside air (OA) intake dampers have a number of typical problems which can cause or amplify IAQ problems. OA dampers which do not close completely can allow moisture and dirt to collect in the spaces and develop into mold germination sites or amplification sites. Poor outside air damper controls can cause problems. A failed freeze thermostat which overrides the OA damper modulated setting can cause the damper to close when it should be open. If the damper is closed when it should be open for makeup air, building pressurization and infiltration of unconditioned air will both become worse. With the dampers closed, the building spaces can overheat even in winter conditions. The most immediate IAQ problem due to inadvertent closing of the intake dampers is lack of ventilation to remove human effluents.

4.3.3 Lack of Chilled Water in Winter Weather

Chillers may be needed even in winter seasons to bring discharge temperatures down to the typical 55°F (12.8°C) for interior spaces. Lack of winter chiller operation at outside temperatures of 50°F (10.0°C) or higher may lead to stuffiness and poor temperature control of interior zones. Chiller controls are often left in a malfunctioning mode in the winter under the impression that the chillers are not needed.

4.3.4 Supply and Return Fan Balancing

Fan air flow tracking is also important to pressurization and thus infiltration as noted above. If the supply fan flow rate is not greater than the return fan flow rate, the conditioned space will need to take in outside air from some other source. Doors can be drawn and held inward allowing large amounts of outside air to be entrained. Variable air volume systems are prone to problems with fan tracking. VAV systems require static pressure sensors to maintain control over a wide range of air flow rates. As pressures drop, sensors are less repeatable and can cause severe fan cycling as the sensor “hunts” for the correct control point. Fan cycling causes occupants to perceive more serious air handling problems.

4.3.5 Return Damper Problems

If the system is using 100% outside air, as in an economizer cycle, the return damper must be fully closed. Leakage of undesired return air into the intake air causes overheating problems. If the return damper is closed to force contaminated air out of the building rather than recirculate a problem, a leaking damper can only worsen the problem.

4.3.6 Improper Control Strategies or Control Malfunctions

Building controls require regular calibration or verification that they are operating properly. Improper control operation and maintenance cause imbalanced systems and poor environmental conditioning which leads to more perceptions of poor air quality and higher cost of operation. Before attempting to set building ventilation to meet IAQ standards all of the controls must be checked for proper operation and calibrated. Air balancing within a system, especially VAV systems, is just as important to proper ventilation.

All of the above areas are related to ventilation of the occupied building spaces. As we have noted, ventila-

tion is not the sole solution to many indoor air quality problems. However, if building ventilation is not properly controlled it may be impossible to solve the problem by other means.

4.3.7 Breathing Zone Ventilation

The area in which the occupants actually breathe is the most important space in the facility when it comes to outside air ventilation. “Breathing Zone Ventilation” (BZV) is the most critical aspect of supplying air to meet the needs of the people. Even if an HVAC system is delivering all of the outside air called for by ASHRAE Standard 62, if the air does not get to the occupants it does no good.

In modern buildings the breathing zone has changed dramatically from non-mechanically ventilated buildings of the past. Office spaces have suffered from repeated divisions of the space down to everyone having one cubicle of space in which to work and breathe. At the same time office space was being reduced and occupant density was increasing, the energy crisis caused ventilation to be reduced even further.

Offices constructed with cubicles don’t need to have the “ceiling components” of lighting, sprinklers, and ductwork moved in order to move or regroup people. The problem this causes is that ventilation is often designed to meet the needs of one large open space. As office cubicles are added and more subdivision of the space takes place, the amount of ventilation air delivered into each individual occupant’s working may be reduced.

In addition to blocking air movement with normal dividers (4 to 6 ft (1.2 to 1.8 m)), building managers allow the use of dividers to create full height walls. When full walls are created with dividers and built-in doorways, they often cut off lighting and supply and return diffusers without concern for the needs of the workers below.

Filing systems, with stored boxes and other items on top of cabinets often approaching the ceiling, contribute further to blocked supply and return air flows. In offices with cubicles constructed of movable walls, the maximum height of stored objects should not exceed that of the cubicle walls.

CO₂ concentrations at working locations can be two to five times the average concentration in an office. CO₂ levels can be measured while doing IAQ investigations.

Solutions to this type of problem obviously cost less than complete redesign and rework of an air distribu-



tion system. In many cases, solutions involving reallocation of space in the office are more easily implemented than mechanical system solutions. They often have the advantage of being visible to the occupants and capitalize on the perceptions of improvement.

Below is a list of potential improvements and areas to avoid when reconfiguring office spaces or looking for needed air movement enhancements.

- a. Limit the height of dividers to that absolutely necessary to meet the office separation needs.
- b. Allow for moving air supply and return openings by doing the initial installation with flexible ductwork in open office areas which are to be furnished with movable dividers. Move the supply and return openings to correspond with wall movements.
- c. Use dividers which are open at the bottom to allow air circulation through the occupied space. In offices with 6 to 8 in. (15.2 to 20.3 cm) spaces at the bottom of dividers, there is little increase in noise levels (carpeted office space) and noticeable improvement in perceived air freshness at desk level.
- d. Build larger cubicles. Cubicles which house several staff members rather than one obviously allow for easier movement of the air.
- e. Build localized air movement controls with small fans or ducting of the air supply system.
- f. Install diffusers designed to mix air better at the ceiling level. Newer diffusers exhibit 20 to 40% better mixing of supply air with existing room air and reduce short-circuiting of the air supply.
- g. Be sure the system is tested and balanced and the inter-zone pressurization is correct before implementing other solutions.
- h. Never allow individuals to redirect air flow with tape or cardboard on diffusers.

- i. When new walls are installed, recheck the air movement and compare the values to those previously recorded. Check with the occupants after the new arrangements have been implemented to ensure there are no new perceptions of problems.

4.4 OCCUPANT SOURCES

Occupant-originated contaminants basically fall into two categories. The first category contains normal human odors, exhaled CO₂, and cosmetic odors. Cosmetic odors can cause allergic reactions in some individuals, but typically only lead to objections by neighbors if one person uses excessive amounts of a product.

This topic, including calculations of the ventilation required to overcome CO₂ exhalation, is covered in Chapter 10 and the Appendices.

Smoking and environmental tobacco smoke are on the decline in the United States. Many buildings (especially privately held corporate buildings, and U.S. Government facilities) no longer allow smoking in open spaces. Some have constructed smoking lounges, other have relegated smoking to outside locations. In either case, the smoking issues themselves are being resolved by the changing process in America's private companies, government facilities, and institutions.

Other human odors must be addressed as part of the psychosocial aspects of group dynamics. If problems become excessive, management should treat the issue as it would any other indoor contaminant.

Cooking, including local coffee services or desktop coffee heaters, can be a problem if there is insufficient ventilation to remove the odors. With HVAC systems and ventilation off, some food and drink odors can become objectionable if allowed to remain in a building overnight, and can be perceived as IAQ problems the following morning. To avoid this issue, many companies now limit the locations where food or coffee may be prepared.

CHAPTER 5

TESTING AND SAMPLING

5.1 INTRODUCTION

Air sampling is used when the contaminants are not obvious, or if symptoms of IAQ problems are present and no specific contaminant can be identified as the cause. Air sampling is used to determine the chemical or particulate makeup of the contaminating factors in the occupied space. It is also used to determine the origin of a contaminant either by sampling at a sufficient number of locations to determine where the contaminant is strongest or by determining its origin by learning the chemical nature of the contaminant and thus deducing its source from the known, possible sources of that particular contaminant.

Air sampling should only be considered as a diagnostic tool after the other, more obvious, evaluation tools have been used. Surveys of the occupants can lead to some ready answers to IAQ problems if people have been observant and odors or other indicators are well known. Knowledge of how the HVAC system functions and how it has been maintained can help a proficient technician with the task of evaluating its current state.

Particular types of contaminants are readily traced, and the source eliminated or the pathway blocked, if the contaminants come from typical sources. Sources discussed earlier such as vehicle exhaust, new furnishings, occupants, and other sources which are not foreign to the environment, do not require air sampling or other forms of formalized testing to determine their origin.

Different types of contaminants require different sampling methods. The following sections will not necessarily discuss details of methods and tools, but will provide an outline, or system, of measurement protocols to define the process.

5.2 GASEOUS PRODUCTS

One of the major problems with sampling for gaseous contaminants is the difficulty of measuring potentially minute amounts of gas molecules with instrumentation generally designed to measure industrial contamination quantities. Occupants may be sensitive to odors or suffer from symptoms of overexposure at very low concentrations.

Gaseous sampling, usually for VOC's, involves some method of collecting a sample of the air which contains a sufficient quantity of the contaminant to "test" with definite results. Also, the person performing the sampling must have enough insight into the types of

problems possible in the building to be able to select test locations and timing of the samples.

Comparison sampling is one of the testing processes which aids the sampling organization and individuals in selecting test locations. Samples taken in an area which has complaints should be compared to samples taken in a reference area, or control location. The control location should be selected to match the occupant demographics, space type, and space usage as the problem area and samples should be taken at the same times and with the same method and frequency as in the problem area. A comparison of these two sets of measurements can then be used to determine if the contaminant differences are sufficient to cause the symptoms in question.

One obvious comparison is to use outside air as a reference. While this may be helpful in some cases, such as testing for fungal spores, it is not likely to be conclusive when looking for subtle chemical vapor, or VOC contaminants. The synergistic effects of the elements in the indoor air (even temperature and humidity) can cause illness symptoms even if the actual concentration of the contaminant is lower than expected.

Gaseous sampling, as with any air sample process, is only an indication of the contaminant level at a single point in time. Check surveys and occupant logs to see if sampling should be done over a longer period of time (e.g. over a full day or over several days).

Gaseous sampling requires more than just the collection of the samples to be of value. Each sample must be evaluated in the laboratory by testing for the contaminants suspected by the investigator. This process is typically more costly than the sampling process itself. Consider testing for a very narrow range of gaseous contaminants if sampling must be done at all, in order to help the client manage the cost of the IAQ investigation.

5.3 ORGANIC

Sampling for organic contaminants requires all the care involved with testing for gaseous contaminants, and the added need for more insight into where and when to take samples.

VOC's (the volatile organic compounds discussed above) are generally investigated as gasses. The other category of organic contaminants, those which are biological in nature, are investigated as life forms in the environment. Biological organic contaminants, or microscopic biological compounds, are referred to by the general term as microbials.



These biological pollutants consist of fungi or mold; insects such as dust mites, pollen, viruses, and bacteria or bacterial decay compounds; and algae. All of these are present in all of our environments regardless of the level of cleanliness (with the possible exception of some clean rooms). However, the concentration is typically not sufficient to cause illness or allergic reactions in most indoor atmospheres. The problems with microbials arise when the living pollutants are supplied with breeding and growth sites. These sites are called “amplification” sites or zones.

Biological contaminants and the resultant problems are increasing due to tighter building envelopes and energy savings strategies of reduced outside air. Any facility which has the potential for standing water to collect for any significant length of time or in which maintenance does not know what to look for to prevent microbial contaminants is likely to suffer from contamination.

Microbial contaminants usually originate from some source other than the building itself or the materials and furnishings inside the building. Biologicals come from the people in the facility, pets or hair and dander carried in by people with animal contact, outside air and entrained plant and animal matter, and indoor plants.

Breeding sites and amplification sites are plentiful in almost any modern building. Breeding grounds for most of the microbials consist only of a dark place with sufficient nutrients and moisture to support the living organisms.

Biological contaminants cause many different types of illnesses and symptoms of illnesses. They are responsible for allergic reactions and irritation responses from the respiratory system, severe respiratory problems, infections, and hypersensitivity reactions. Microbials can cause such a wide variety of illness symptoms which parallel other human health problems that it is difficult to analyze the problems they cause.

One of the most noted of the microbial contaminant health effects is legionella pneumonitis or legionnaire’s disease. The typical locations and systems required for development, growth, and distribution for legionella are present most buildings. Cooling tower contamination and insufficient cleaning is implicated in many cases but any area with moisture and nutrients will suffice for the bacteria to develop.

While all of the life forms noted above exist in some concentration in all buildings, the most prevalent form of microbial contamination is mold. Viable mold spores (those which can reproduce) are present in the air we breath in any location. Mold spores are present in outside air. In fact, one of the most common methods of evaluating a building for mold spore content is to relate the indoor air concentration to the ambient outdoor concentration. It is difficult to completely separate the issues of molds and VOC’s because mold and fungal contamination emit volatile organic compounds. The odor encountered in a wet basement is the most common example of VOC’s from fungi.

Mold and fungal problems alone can cause health effects encompassing those from the entire range of microbial contamination. Molds cause infectious diseases, allergic reactions such as rhinitis and asthma, pneumonias, cancers, immune disorders, mucous membrane inflammation, and other respiratory irritations.

Insects, their excreted matter, and animal dander (specifically, cat dander) are the next most prevalent category of microbial contamination found in occupied spaces. Cat dander is present in any building in which people who have contact with cats are present. Allergic symptoms and reactions happen for some individuals with extremely small concentrations of animal dander. Since the contaminant is not found naturally in the work environment, it can be difficult for the investigator to trace and identify.

Buildings which have any porous surfaces (carpeting, draperies, furnishings, or wall panels) will have dust mites. Dust mites are microscopically small insects which breed and grow in any of these porous areas. They feed on the human skin cells, dirt, dust, food particles, and plant and animal matter which is tracked in, or carried in, by the occupants. Dust mites are found most heavily in carpeting and bedding.

Other mites originate in household animals and rodents. Larger insects more typically cause problems due to the spread of other diseases of excreted matter.

Investigation for microbial contamination is initially limited to visual methods and air sampling to determine the presence of the suspected biological contaminant.

Visual inspections can identify potential breeding, growth, and amplification sites in the building. Any evidence of moisture should be noted (see the walkthrough forms in Appendix A) and maintenance or

cleaning procedures enhanced where any growth site is suspected. Testing, such as air sampling for viable mold spore counts, should be done before and after to determine if the new activities are leading to reductions in concentration levels.

Air sampling and the follow-up laboratory work should be contracted to qualified firms due to the technical nature of doing contaminant counts and speciation (identification of the type of contaminant). Methods for sampling are listed in Table 5-1.

Guidelines for the majority of the microbial contaminants do not exist. The one area which has been studied sufficiently to result in some specific guides is that of fungal counts. The ACGIH recommends that indoor viable mold spore counts be less than half of the ambient outdoor level and that the speciation tests for both indoor and outdoor samples are not significantly different.

Colony-forming-units (CFU) are mold spores which can reproduce. The number of CFU's in a given volume of air is used for measurement and comparison purposes. Generally the industry also adds limits of 300 cfu/m³ of common fungi and those counts which exceed 500 cfu/m³ should be investigated even without specific illness symptoms.

5.4 PARTICULATES

Particulates are either solid or liquid materials. Particulates captured and distributed by the HVAC system can become serious in terms of spreading problems and causing illness if exposures exceed acceptable levels. Particulates from certain products, such as those found in environmental tobacco smoke, can also contribute to odors in the workplace.

Particulates fall into several categories based on their origin. The particulate types, their origins, some specific details, and examples are listed in Table 5-2.

Airborne particulates range in size from molecular to visible to the naked eye. Mineral fibers in indoor air are reflective and become visible in sunlight or strong, white indoor light. However, the significance of the size of airborne particulates lies in the ability of the human respiration system to capture the particles.

Particles which are 3 µm in diameter and smaller can penetrate to the human lung during inhalation and are said to be "respirable." Particles from 3 to 10 µm in diameter penetrate the upper respiratory passages but

are generally not respirable (*i.e.* they will be trapped by the cilia in breathing passages or will not penetrate lung tissue). Particles larger than 10 µm in diameter typically do not get into the ciliated portions of the respiratory system.

Particles which penetrate to the lung tissue can be lodged in the tissue and become carcinogenic. Radon progeny (the radioactive, solid particles emitted during the decay of radon gas) lodged in human lung tissue is known to cause cancer with long term exposure as are other particulates such as asbestos. Any foreign matter penetrating to the alveoli of the lungs can cause serious illness.

Particles are created by many processes normally found within human occupied spaces. Combustion of tobacco, fossil fuels, and wood and plant matter contribute a wide range of particle types and sizes. Condensation of vapors contributes particles of liquids to the airstream. Spraying liquids, insulation, paint, and other products add vapors and particulates from minerals like pigments. Other particles are created by human occupation. Dirt, earth dusts, and plant matter can fall into the latter category.

Standards for particulate exposure vary widely outside the United States. Most of the standards are for limits on outside or ambient air. However, the United States (through the EPA) and Canada specify indoor standards of exposure to particulates as well. The United States EPA specifies a limit of 50 µg/m³ for exposure to particles averaging 10 µm in diameter. ASHRAE also recommends this same exposure limit, while the Canadian government's standard is 40 µg/m³ with a size of 2.5 µm.

Sampling methods for particulates usually are based on collecting an air sample of sufficient size to carry measurable amounts of the suspected particulate. The sample is tested by weight of contaminant, counts of particles, and various lighting processes used to illuminate the particles for both size and characterization. Airborne particulates may also be measured by the amount of staining they create on surfaces in the occupied area being tested. Surface stains can be defined by the change in reflectivity of the surface or by the color caused by deposition of the contaminating particles.

Air sampling and laboratory verification of the quantity and characteristics of the samples should be done by a qualified person who is well-versed and practiced in sampling and lab techniques, hazards, and cautions.



Microbial Sampling	Description	Comments
Anderson Impactor	Microbials of specific sizes (by filters) are deposited on agar plates for growth and speciation testing.	Most widely accepted method for determining contamination with respect to particle size.
Surface Sample Impactor	Similar to Anderson impactor but uses Rodac plates for impact collection medium.	Less efficient than the Anderson impactor.
Agar Impactor	Uses slits in the air sampling system through which biologicals are deposited on agar plates.	Larger instrumentation but similar in efficiency to the Anderson impactor.
Sedimentation Plates	Microbials are allowed to collect naturally on agar plates at selected locations in and out of the building.	Long term exposure can lead to contamination of the testing medium with soils, dust, and dirt making analysis more difficult. Inexpensive but not in common use.

Table 5-1 Air Sampling Methods for Microbial Contaminations

Particulate Category	Origins	Examples	Sizes
Animal	Occupants, pets, soils tracked in from outside, effluents originating in ill occupants.	Human skin and hair, pet hair, human effluents, insect parts, insect feces, bacteria and viruses.	Ranging from bacteria less than 0.5 μm in diameter to human hair up to 150 μm in diameter.
Vegetable/Plant	Nearby outside vegetation, indoor plants, food-stuffs, tracked in plant matter, wet areas supporting mold growth.	Pollens, mold spores, dead plant matter allowed to rot, food particles ground into carpets and emitted when walked on.	Molds and pollens between 5 and 10 μm in diameter up to rough plant particles over 100 μm .
Earth/Mineral	Atmospheric dust, soil, carbon and other mineral dust, man-made fibers constructed from combinations of materials.	Asbestos, glass-wool fibers, clay dust, wall board dust, fibers captured in furniture during manufacture and during use.	Vapors from minerals at less than 0.5 μm in diameter up to the limits of inhalable (not necessarily respirable) particle sizes over 100 μm in diameter.
Radioactive	Soil gasses.	Radon progeny released into lower level spaces.	Molecular.
Combustion	Tobacco smoking, wood, leaves and refuse burning in surrounding areas, wood stoves and fueled appliances which are not properly adjusted.	ETS particles, carbon, wood fibers, exhaust particles from internal combustion engines (diesel, gasoline, and propane), industrial exhaust vapors and particulates.	Ash and ETS particles from 1.0 μm in diameter to over 100 μm in diameter.

Table 5-2 Categories of Airborne Particulates

PHASE II

IDENTIFICATION, EVALUATION, AND RESOLUTION OF IAQ ISSUES

CHAPTER 6

EVALUATION AND PROBLEM STATEMENT

Phase II of this manual provides explanations of methods to define, resolve, and mitigate indoor air quality issues. Any building in which there are IAQ problems, or suspected IAQ problems, will require the services of trained contractors and technicians to determine the nature of the problem and to use their expertise with the HVAC equipment and systems to provide cost effective solutions.

Chapters 6 through 12 should be read in the presented order. This will help you to understand the general nature of the IAQ problem definition, verification, and resolution process from start to finish. The material can also be used to help determine a process for working with a client to characterize and solve a specific problem.

Part of the solution is contained in the problem definition which is obtainable through interviews, surveys, investigative, and measurement methods. The basic tools to perform these functions is included in Chapter 6. The chapters which follow provide further means to narrow the problem to a particular contaminant, area, or type of issue.

The forms included in the Appendices will help to gather data during the interview, survey, or investigative process.

The sections which follow the investigative details will help you to prepare an IAQ proposal and provide more details on how you can assist the owner in locating, solving, and preventing further IAQ problems.

6.1 MAGNITUDE OF THE SYMPTOMS

The magnitude, or seriousness, of the indoor air quality problem in any building is a combination of the actual state of the environment inside the building and the condition and sensitivities of the occupants. The building conditions which determine their part of the problem consist of a combination of factors including: age, trapped moisture, remodeling conditions, ventilation rates, functions inside the building, and maintenance and cleaning operations.

The occupants of a building vary in sensitivity based on a similarly wide variation of conditions. Among the factors which can affect how a person is impacted by airborne (or otherwise distributed) contaminants in a building are: age, gender, allergic reaction, other illnesses or unrelated symptoms, psychosocial conditions of the work environment, and emotional condition.

The EPA, along with many other researchers including the NEMI study cited earlier in this manual, have classified indoor air quality problems based on the impact they can have on the occupants and the owners or operators of the building. The major factor in these evaluations of problem magnitude is cost.

The EPA lists three primary categories of financial loss due to IAQ problems in addition to the value of the personal time spent addressing medical problems. The three categories of loss are 1) material soiling or damage, 2) medical evaluation and treatment, and 3) lost productivity.

Losses to material and equipment include soiling which can reduce the life of furnishings and equipment in addition to increasing the cost of cleaning. Most indoor contamination does not directly deteriorate material surfaces (like smog can affect outside statuary) but the added cleaning can shorten product life due to deteriorated appearance. Losses of material could also include equipment which is damaged by higher levels of dust, dirt, and excess moisture. Table 6-1 shows some of the possible effects of indoor pollutants on various materials.

Medical costs for occupants with conditions related to IAQ problems include doctor and hospital visits, medication and, in extreme cases, emergency support services and surgery. The total medical risk of IAQ also includes insurance costs which are based on payout histories.

Productivity may be the single largest component of the cost effects of IAQ. As noted earlier, the NEMI study concluded there was an annual loss of nearly \$60 million in the United States alone due to lost productivity and health from IAQ. This figure does not include the medical treatment costs in the previous paragraph.

There are many ways to calculate the losses noted above. In a report to Congress, the EPA listed Market Based Costs, Contingent Values, and Damage Costs as the means to evaluate the loss of product, materials, service or reduced property values. On the occupant side, the list of losses includes the direct medical expense, loss of pay, and loss of future earnings potential in cases of extreme illness.

Studies concluded as early as 1988 (by NEMI and Woods) estimated productivity increases as low as 0.5% could offset the additional costs of energy and operations incurred to improve the indoor environment. As labor costs become the dominant factor in more industries this number could be even lower.



Materials	Type of Damage	Pollutants	Other Factors
Metals	Corrosion, tarnishing.	Sulfur oxides and other gasses.	Moisture, air, salt, microorganisms, particulate matter.
Paint and Organic Coatings	Surface erosion, discoloration, soiling.	Sulfur oxides, hydrogen sulfide, particulate matter.	Moisture, sunlight, ozone, microorganisms.
Textiles	Reduced tensile strength, soiling.	Sulfur oxides, nitrogen oxides, particulate matter.	Moisture, sunlight, ozone, physical wear.
Textile Dyes	Fading, color change.	Nitrogen oxides, ozone.	Sunlight.
Paper	Embrittlement, soiling.	Sulfur oxides, particulate matter.	Moisture, physical water.
Magnetic Storage Media	Loss of signal (information.)	Particulate matter.	Moisture, heat, wear.
Photographic Materials	Micro blemishes, "sulfiding."	Sulfur oxides, hydrogen sulfide.	Moisture, sunlight, heat, other acidic gasses, particulate matter, ozone and other oxidants.
Rubber	Cracking.	Ozone.	Sunlight, physical wear.
Leather	Weakening, powdered surface.	Sulfur oxides.	Physical wear.
Ceramics	Changes in surface appearance.	Acid gasses, hydrogen fluoride.	Moisture, microorganisms.

Source: EPA

Table 6-1 Air Pollution Effects on Materials

While the magnitude of the total IAQ problem is difficult to define, at least in average terms, the real costs or losses to an individual can be determined if the symptoms and effects can be traced to specific causes. Identification of these relationships and the means by which to mitigate the problem are the next steps.

6.2 IDENTIFYING SYMPTOMS AND AUDIT PROCEDURES

6.2.1 Management Team

Chapter 12 covers the workings of the indoor air quality management team in complete detail from development to ongoing operation. This section will highlight the need for a team of people who can act on behalf of the company, building owner, or facility manager for the purpose of achieving and maintaining a quality indoor environment.

The team's first action is usually to develop the policy described in Chapter 12. After the policy is developed, the team is responsible for:

- Receiving IAQ complaints.
- Responding to IAQ problems.
- Addressing staffing needs for IAQ work on the HVAC systems.
- Tracking the budget, expenses, and proposals for IAQ.

Recognition of the team's objectives by management and building occupants is important to the team's success. The occupants need to know where to take concerns, complaints, and questions. They also will want to know who is responsible for their environment and

for their health. Do not overstaff the IAQ team, but have enough people assigned to handle the work.

Often the IAQ team has members who are outside service providers or consultants. In this case the members of the outside consultants should also be aware of overall corporate policies and restrictions which might affect their actions. A senior member of the IAQ team should also sit on corporate staff level meetings on some regular schedule to report issues, successes, and needs.

Any contractor which handles installation or service of a building's HVAC equipment can assist a building owner or manager in the development of an IAQ team. The contractor is then in a position to offer to serve as a member of that team to properly address and manage the indoor air issues of the building. Contractors who have installed, serviced, or otherwise learned the ductwork systems and layout for a building are in an excellent position to serve building management in this manner.

6.2.2 Walkthroughs

One of the building manager's most valuable tools in the effort to indoor air quality problems is the building walkthrough. Operating, maintenance, and engineering staff spend most of their time in the occupied spaces of the building and should use the walkthrough concept and process to add information on the building status and day-to-day workings to more formal IAQ measurements.

A planned walkthrough includes a checklist (Table 6-2) using the equipment and building forms in Appendix A. The reference to "Observation Sheets" ensures that all of the noted potential IAQ problems will be addressed. That form is used to record incidents or conditions which might become an IAQ issue noticed as the operating staff is working on other areas. The checklist in this walkthrough is a more defined list of items to verify, check, or observe.

A formal walkthrough should also include checking each HVAC system and component. The EPA forms included in Appendix A of this manual are excellent guides for HVAC system evaluation. The forms are also part of the EPA's book, "Building Air Quality — A Guide for Building Owners and Facility Managers."

Other than HVAC issues (covered by the EPA forms in Appendix A), the walkthrough checklist should in-

clude the items presented in Table 6-2 for every uniquely ventilated space in the building. This includes not only each HVAC system and each of its zones, but also areas known to have distinct air flow, ventilation or other issues due to open windows, building pressurization or blocked air flow.

6.2.3 Maintenance Records

The facility operations or engineering department normally keeps the maintenance records. The same people are responsible for collecting and maintaining the indoor air quality records. Much of the material, drawings, and plans, as well as the knowledge of where building equipment is located, is in this department.

Maintenance for IAQ is recorded on the same forms as the equipment checklist. In addition, keep records of who has been trained to perform each of the tasks related to air quality, building maintenance, cleaning, and any operation which introduces foreign contaminants into the building.

The lists which should generally be maintained are the maintenance records. Local authorities (state and municipal) are reviewing the OSHA proposed IAQ regulations as consideration for their own regulation or using components of the proposal.

6.2.4 Conducting Surveys

Occupant surveys to gather information about a real or perceived problem with IAQ can be a very sensitive task. Those who conduct the survey should be aware of the feelings of the people involved and do everything to keep them comfortable.

Survey settings should also be comfortable to help the respondents feel more positive about the possibility they might help others. If occupants are being interviewed one-on-one (usually the best method if feelings and perceptions are widely varied), the interviewer should try to make each new person comfortable with brief introductions and encouraging comments.

In preparation for conducting surveys, read each of the questions through and write a brief answer to each. After completing this step, re-read all the questions out loud. The total time for these two sequences will be the approximate time needed for each interview. Finally, allow for a minute or two between survey participants to prepare for the next person.

