PDHonline Course M187 (4 PDH)

HVAC Systems and Indoor Air Quality

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HVAC Systems and Indoor Air Quality

Course Content

"Indoor air quality is defined as the nature of air that affects the health and well-being of occupants. According to ASHRAE Standard 62-2001 acceptable indoor 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." Good indoor air quality involves adequate oxygen, low contaminant levels, and the absence of irritating odours.

Section -1 FACTORS AFFECTING INDOOR AIR QUALITY (IAQ)

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

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

1) *Source:* there is a source of contamination or discomfort indoors, outdoors, or within the mechanical systems of the building.
2) *HVAC:* the HVAC system is not able to control existing air contaminants and ensure thermal comfort (temperature and humidity conditions that are comfortable for most occupants).
3) *Pathways:* one or more pollutant pathways connect the pollutant source to the occupants and a driving force exists to move pollutants along the pathway(s).
4) *Occupants:* building occupants are present.

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

SOURCES OF INDOOR AIR CONTAMINANTS

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

Sources	Examples
Contaminated outdoor air	Pollen, dust, fungal spores, industrial pollutants, exhaust from vehicles on nearby roads or in parking lots, or garages, loading docks, odours from dumpsters, re-entrained (drawn back into the building) exhaust from the building itself or from neighbouring buildings, unsanitary debris near the outdoor air intake
Soil gas	Leakage from underground fuel tanks, contaminants from previous uses of the site (e.g., landfills), pesticides
Equipment *HVAC system*	• Dust or dirt in ductwork or other components • Microbiological growth in drip pans, humidifiers, ductwork, coils • Improper use of biocides, sealants, and/or cleaning compounds • Improper venting of combustion products • Refrigerant leakage

Sources	Examples
Non-HVAC equipment	• Emissions from office equipment (volatile organic compounds, ozone) • Supplies (solvents, toners, ammonia) • Emissions from shops, labs, cleaning processes • Elevator motors and other mechanical systems
Human Activities *Personal activities*	• Smoking • Cooking • Body odour • Cosmetic odours
Housekeeping activities	• Cleaning materials and procedures • Emissions from stored supplies or trash • Use of deodorizers and fragrances • Airborne dust or dirt (e.g., circulated by sweeping and vacuuming) • Micro organisms in mist from improperly maintained cooling towers • Airborne dust or dirt • Volatile organic compounds from use of paint, caulk, adhesives, and other products • Pesticides from pest control activities • Emissions from stored supplies
Building Components and Furnishings	• Locations that produce or collect dust or fibres • Textured surfaces such as carpeting, curtains, and other textiles • Open shelving • Old or deteriorated furnishings • Materials containing damaged asbestos
Unsanitary conditions and water damage	• Microbiological growth on or in soiled or water-damaged furnishings • Microbiological growth in areas of surface condensation • Standing water from clogged or poorly designed drains • Dry traps that allow the passage of sewer gas
Chemicals released from building components	• Volatile organic compounds or • Inorganic compounds
Special use areas and mixed use buildings	• Smoking lounges • Laboratories • Print shops, art rooms • Exercise rooms • Beauty salons • Food preparation areas

Each of these contaminants affects humans in one way or other. Given our present knowledge, it is difficult to relate complaints of specific health effects to exposures to specific pollutant concentrations, especially since the significant exposures may be to low levels of pollutant mixtures.

HVAC SYSTEM DESIGN AND OPERATION

The definition of good IAQ [EPA, 1992] includes; the maintenance of acceptable temperature and relative humidity [thermal comfort]; the introduction and distribution of adequate ventilation [outside] air and the control of airborne contaminants, and. In most buildings, these elements are provided by mechanical HVAC system.

Thermal Comfort

Thermal comfort is very important to occupant satisfaction. A number of variables interact to determine whether people are comfortable with the temperature of the indoor air. The activity level, age, and physiology of each person affect the thermal comfort requirements of that individual.

Proper temperature and humidity control are essential in maintaining good indoor air quality. For example, inadequate cooling or moisture reduction can increase the possibility of mold (fungal) production. Airflow control or using the heating/cooling fan to maintain airflow is essential in keeping the occupied space uniformly heated and cooled.

Temperature is a factor in Thermal Comfort

ASHRAE 55-1992 suggests the following temperature ranges for overall thermal comfort.

Season	Clothing	Optimum Temperature	Temperature range
Winter	heavy slacks, long-sleeve shirts and sweaters	22°C 71°F	20-23.5°C 68-75°F
Summer	light slacks, and short sleeve shirt	24.5°C 76°F	23-26°C 73-79°F

While no single environment can be judged satisfactory by everybody, most people will achieve comfort if it meets the following criteria:

1) ***Uniformity of temperature:*** Uniformity of temperature is important to comfort. The temperatures should not vary within single zone or change suddenly or drastically. Space temperature shall be uniform and between 68-79°F, slightly cooler in winter and slightly warmer in summer. ISO recommends that floor temperature be between 19- 26°C and ASHRAE recommends 18-29°C.

2) ***No Temperature Stratification***: Temperature stratification in simple word means vertical temperature difference between feet and head. It is a common problem caused by convection, the tendency of light- warm air to rise and heavier-cooler air to sink. If air is not properly mixed by the ventilation system, the temperature near the ceiling can be several degrees warmer than at floor level.

3) ***Minimizing Exposure Effects:*** Absence of radiant fields and no cold window, cold floors, warm radiators or radiant solar heat at windows is prerequisite to thermal comfort. Radiant heat transfer may cause people located near very hot or very cold surfaces to be uncomfortable.

   Buildings with large window areas sometimes have acute problems of discomfort due to radiant heat gains and losses. Radiant temperature discomfort can be isolated by insulating surfaces that radiate heat or cold, like windows, floors, walls, and equipment.

4) ***Absence of Drafts:*** Large vertical surfaces can also produce a significant flow of naturally-convecting air, producing complaints of draftiness. As a rule of thumb, horizontal temperature differences should not exceed 10°C and vertical temperature differences should not exceed 5°C.

To avoid draft, ASHRAE suggests that air speeds should be below 0.2 metres/second (m/s) with ventilation systems that create 30-60% turbulence intensity. Use ceiling diffusers with 45° or 90° angles over 10° angles because 10° angles can cause draught at the head; Circulated air should be no more than 2°F different from the ambient space temperature.

Humidity is a factor in Thermal Comfort

ASHRAE 55-1992 recommends the relative humidity (RH) to be maintained between 25 and 60% during occupied periods, 70% maximum during unoccupied periods. Usually air is humidified to between 25 -45% during winter and dehumidified to below 60% during summer. Any figure outside this range shall produce discomfort and IAQ problems. Humidity extremes are possible in the building spaces which are at negative pressure due to an imbalance between the outside air intake and the exhaust system. Since most air conditioning systems are designed to control room temperature, the RH can swing drastically when negative pressure is present, when a large amount of outside air is being supplied through the unit, or during light load conditions. The problems of RH variations on IAQ are:

1. Raising relative humidity reduces the ability to lose heat through perspiration and evaporation; the effect is similar to raising the temperature.
2. Mold, mildew, and fungal growth will proliferate in a building if the RH in the space is allowed to exceed 60% on a regular basis. Dust mites will also become a problem above this level. Musty odours and visible signs of microbial growth on walls, windows, and diffusers are good indicators of a developing IAQ problem.
3. Low RH on other hand shall result in skin dryness, mucous membrane irritation, and discomfort with skin moisture. It also results in static electricity that may interfere with electronic equipments and give you a shock.

Ventilation is a factor in IAQ

Outdoor air contains about 21 per cent O_2 and 0.03 per cent CO_2 on a volume basis (the remainder being mainly nitrogen). Significant variations in these proportions can render it unfit for human use. For prolonged exposure a minimum concentration of 16 per cent O_2 and a maximum concentration of 0.5 per cent CO_2 (sometimes extended to 1 ½ per cent) are commonly accepted standards.

A person, when seated, usually inhales about 18 cu ft of air per hr. The exhaled air contains about 16 per cent O_2 and about 4 per cent CO_2. Thus, if only 18 cu ft per hr of fresh air were provided for each person in a continuously occupied space, the concentrations of CO_2 would exceed the permissible levels (ASHARE recommends the CO_2 levels should not exceed 1000ppm). Consumption of O_2 and production of CO_2 increase with activity, and ventilation requirements increase correspondingly. For people who are standing, the values are about 50 per cent higher than for those seated. Therefore supplies of outside air in excess of that required controlling the effect of respiration on O_2 and CO_2 levels plus for pressurization of the building are required. The building need to be positive pressurized so that uncontrolled infiltration is prevented.

ASHRAE Standard 62-1999: “Ventilation for Acceptable Indoor Air Quality” is a nationally accepted standard of care for ventilation rates, indicating how much outside air per person is required for each type of occupancy. A table of outdoor air quantities recommended by ASHRAE is reproduced below.

FIGURE B-2: Selected Ventilation Recommendations

Application		Occupancy (people/1000 ft²)	Cfm/person	Cfm/ft²
Food and Beverage Service	Dining rooms	70	20	
	Cafeteria, fast food	100	20	
	Bars, cocktail lounges	100	30	
	Kitchen (cooking)	20	15	
Offices	Office space	7	20	
	Reception areas	60	15	
	Conference rooms	50	20	
Public Spaces	Smoking lounge	70	60	
	Elevators			1.00
Retail Stores, Sales Floors, Showroom Floors	Basement and street	30		0.30
	Upper floors	20		0.20
	Malls and arcades	20		0.20
	Smoking lounge	70	60	
Sports and Amusement	Spectator areas	150	15	
	Game rooms	70	25	
	Playing floors	30	20	
	Ballrooms and discos	100	25	
Theaters	Lobbies	150	20	
	Auditorium	150	15	
Education	Classroom	50	15	
	Music rooms	50	15	
	Libraries	20	15	
	Auditoriums	150	15	
Hotels, Motels, Resorts, Dormitories	Bedrooms			30 cfm/room
	Living rooms			30 cfm/room
	Lobbies	30	15	
	Conference rooms	50	20	
	Assembly rooms	120	15	

SOURCE: ASHRAE Standard 62-1989, Ventilation for Acceptable Air Quality

The ventilation rates specified by ASHRAE effectively dilutes the carbon dioxide and other contaminants created by respiration and other activities; it supplies adequate oxygen to the occupants; and it removes contaminants from the space. The ventilation rates greater than by ASHARE criteria are sometime required controlling odours and where cooling is not provided to offset heat gains.

Control of Odours

The sources for odour are many: body odours, tobacco smoke, vehicle exhaust, food preparation, garbage odours, finishing materials, furnishings and even the wetted coils of air conditioning systems as they become dirty. The outdoor air itself may be an important source in areas where there is serious air pollution. One technique for controlling odours is to dilute them with outdoor air. The second technique may use the gaseous filtration based on principle of adsorption. The adsorbent material is usually activated charcoal, which is very effective in removing the VOC's.

The ventilation rates for odour control are dependent upon the kind of activity and may vary from 5 to 50 CFM per person. For instance in the bars or pubs where smoking is allowed, the values are sometimes as high as 50 CFM.

Control of Airborne Particles

There are a number of other items that can affect indoor air quality. From cigarette smoke to cooking odours to ozone from laser printers all of these can add to the challenges of maintaining good indoor air quality. A variety of airborne particles, such as dust, smoke, pollens and organisms are contained in the outdoor air and are brought indoors along with the ventilation air. Lot of contaminants are generated indoors by the activities of the occupants. Limiting the concentrations of these contaminants is an important aspect of air quality control. One technique for controlling contaminants is to dilute them with outdoor air. Dilution can work only if there is a consistent and appropriate flow of supply air that mixes effectively with room air. The term *"ventilation efficiency*" is used to describe the ability of the ventilation system to distribute supply air and remove internally generated pollutants. Researchers are currently studying ways to measure ventilation efficiency and interpret the results of those measurements. The alternative technique uses dilution as well as isolation or removal of particles through dedicated exhaust systems. This technique is much more effective compared to dilution when the nature of contaminant is known.

HVAC System design

Two of the most common HVAC designs used in modern public and commercial buildings are *constant volume* and *variable air volume* systems. Constant volume (CAV) systems are designed to provide a constant airflow and to vary the air temperature to meet heating and cooling needs. The percentage of outdoor air may be held constant, but is often controlled either manually or automatically to vary with outdoor temperature and humidity. Controls may include a minimum setting that should allow the system to meet ventilation guidelines for outdoor air quantities under design conditions. CAV system is usually provided for a single zone. A zone is defined as a space or group of spaces in a building having similar heating and cooling requirements throughout its occupied area so that comfort conditions may be controlled by a single thermostat.

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

Good quality design, installation, and testing and balancing are critically important to the proper operation of all types of HVAC systems, especially VAV systems, as are regular inspections and maintenance.

Ductwork System

Having the appropriate number of returns (cold air returns) and supply grills can have a great affect on Indoor Air Quality. Not enough returns can reduce the effectiveness of proper heating and cooling and can severely reduce the ability to move all of the air or reduce the moisture levels in the occupied space. This can also affect filtration of the air.

Filtration System

The ability to reduce/remove a significant level of the respirable sized (less than 2 microns) airborne particles is essential in maintaining good indoor air quality.

The lack of good filtration and ventilation can also add to significant challenges in providing a healthy indoor environment. The air filters that come with any heating/cooling system are primarily just a very light duty fiberglass media or washable sponge type media. In either case, these air filters are designed to only keep the blower/motor assembly clean, resulting in indoor air quality problems. They were never intended filter out small or respirable sized particles, gases or odours for the occupied space. These OEM air filters don't remove any mold or bacteria or any of the fine airborne dust.

Air Leakage

Air leakage is the infiltration of air through the building envelope, which depends on the air tightness of the envelope and the pressure difference across it caused mainly by wind and temperature differences between the inside and outside. Leaky buildings are more costly to heat and more difficult to ventilate properly than relatively airtight buildings. Sealing large cracks and openings in the exterior wall and around windows is one good way to improve air tightness.

Building Pressurization

Another common cause of IAQ problems in hot and humid climates is negative building pressure. Negative building pressure can occur through the improper design and operation of the exhaust systems in a building. Operating exhaust fans without the outside air being compensated through the air-handling system will result in negative pressure in the building. Negative pressure in a building allows uncontrolled infiltration through doors and the exterior envelope of the building. This will typically make the building feel drafty and difficult to heat in cold climates and muggy or musty in hot and humid climates since unconditioned outside air is being constantly introduced into the building through uncontrolled infiltration.

POLLUTANT PATHWAYS AND DRIVING FORCES

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

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

HVAC system is pathway for pollutants

The HVAC system is generally the predominant pathway and driving force for air movement and distribution of contaminants. The large buildings are divided into multiple zones each having independent HVAC system or control. But still the contaminants can flow from one zone to another because of building obstructions and people movement. For example, as air moves from supply registers or diffusers to return air grilles, it is diverted or obstructed by partitions, walls, and furnishings, and redirected by openings that provide pathways for air movement. On a localized basis, the movement of people has a major impact on the movement of pollutants. Some of the pathways change as doors and windows open and close. It is useful to think of the entire building — the rooms and the connections (e.g., chases, corridors, stairways, elevator shafts) between them — as part of the air distribution system. Air moves from areas of higher pressure to areas of lower pressure through any available openings. A small crack or hole can admit significant amounts of air if the pressure differentials are high enough (which may be very difficult to assess.)

Building Stack effect

Stack effect is the pressure driven flow produced by convection (the tendency of warm air to rise). The stack effect exists whenever there is an indoor-outdoor temperature difference and becomes stronger as the temperature difference increases and also with the height of the building. As heated air escapes from upper levels of the building, indoor air moves from lower to upper floors, and replacement outdoor air is drawn into openings at the lower levels of buildings.

Stack effect in buildings can have negative effects on IAQ viz. the temperature differences, uncontrolled interior pressure differentials, reduced ventilation. Stack effect airflow can transport contaminants between floors by way of stairwells, elevator shafts, utility chases, or other openings.

The building and system design should be able to counterbalance this effect.

Wind effect

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

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

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

BUILDING OCCUPANTS

The commercial and institutional buildings typically have a much higher density of people and equipment. Maintaining good indoor air quality is more challenging in these types of facilities.

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

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

1. Allergic or asthmatic individuals
2. People with respiratory disease
3. People whose immune systems are suppressed due to chemotherapy, radiation therapy, disease, or other causes
4. Contact lens wearers

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

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

A single indoor air pollutant or problem can trigger different reactions in different people. Some may not be affected at all.

Information about the types of symptoms can sometimes lead directly to solutions.

However, symptom information is more likely to be useful for identifying the timing and conditions under which problems occur.

Common Complains related to IAQ

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

- Headache

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

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

“Health” and “comfort” are used to describe a spectrum of physical sensations.

For example, when the air in a room is slightly too warm for a person’s activity level, that person may experience mild discomfort. If the temperature continues to rise, discomfort increases and symptoms such as fatigue, stuffiness, and headaches can appear.

Some complaints by building occupants are clearly related to the discomfort end of the spectrum. One of the most common IAQ complaints is that “there’s a funny smell in here.” Odours are often associated with a perception of poor air quality, whether or not they cause symptoms.

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

Sick Building Syndrome (SBS)

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

1. The combined effects of multiple pollutants at low concentrations
2. Other environmental stressors (e.g., overheating, poor lighting, noise)
3. Ergonomic stressors
4. Job-related psychosocial stressors (e.g., overcrowding, labour-management problems)
5. Unknown factors

Building-related illness (BRI)

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

Multiple Chemical Sensitivity (MCS)

A small percentage of the population may be sensitive to a number of chemicals in indoor air, each of which may occur at very low concentrations. The existence of this condition is known as *“multiple* *chemical sensitivity" (MCS).* MCS is not currently recognized by the major medical organizations, but medical opinion is divided, and further research is on.

Sometimes several building occupants experience rare or serious health problems (e.g., cancer, miscarriages, Lou Gehrig's disease) over a relatively short time period. These clusters of health problems are occasionally blamed on indoor air quality, and can produce tremendous anxiety among building occupants. State or local Health Departments can provide advice and assistance if clusters are suspected.

They may be able to help answer key questions such as whether the apparent cluster is actually unusual and whether the underlying cause could be related to IAQ.

Section -2 CONTROLLING INDOOR AIR PROBLEMS

Section 1 introduced the idea that indoor air quality problems result from interactions between contaminant source, building site, building structure, activities within the building, mechanical equipment, climate, and occupants. Efforts to control indoor air contaminants change the relationships between these factors. There are many ways that people can intervene in these relationships to prevent or control indoor air contaminant problems. Control strategies can be categorized as:

1) Source control
2) HVAC control
   a. Ventilation
   b. Air cleaning
3) Exposure control

Successful mitigation often involves a combination of these strategies.

SOURCE CONTROL

All efforts to prevent or correct IAQ problems should include an effort to identify and control pollutant sources.

Source control is generally the most cost effective approach to mitigating IAQ problems in which point sources of contaminants can be identified. In the case of a strong source, source control may be the only solution that will work.

The following are categories and examples of source control:

1) ***Remove or reduce the source***
   a. Prohibit smoking indoors or limit smoking to areas from which air is exhausted, not recirculated (NIOSH regards smoking areas as an interim solution)
   b. Relocate contaminant-producing equipment to an unoccupied, better ventilated, or exhaust-only ventilated space
   c. Select products which produce fewer or less potent contaminants while maintaining adequate safety and efficacy modify other occupant activities
2) ***Seal or cover the source***
   a. Improve storage of materials that produce contaminants
   b. Seal surfaces of building materials that emit variable organic compounds (VOCs) such as formaldehyde
3) ***Modify the environment***
   a. After cleaning and disinfecting an area that is contaminated by fungal or bacterial growth, control humidity to make conditions inhospitable for regrowth
   b. Source removal or reduction can sometimes be accomplished by a one-time effort such as thorough cleaning of a spill.

In other cases, it requires an ongoing process, such as establishing and enforcing a non-smoking policy.

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

In some cases, modification of the environment is necessary for effective mitigation. If the indoor air problem arises from microbiological contaminants, for example, disinfection of the affected area may not eliminate the problem.

Regrowth of microbiological could occur unless humidity control or other steps, such as adding insulation to prevent surface condensation, are taken to make the environment inhospitable to microbiological.

HVAC CONTROL

Ventilation Strategies to control Odour and Airborne Particles

Indoor air quality (IAQ) refers to the quality of air within a space while ventilation is the method of diluting indoor air with air from outdoors, or with cleaned indoor air. Ventilation is a key principle of improving IAQ. This approach can be effective either where buildings are under ventilated or where a specific contaminant source cannot be identified. Ventilation can be used to control indoor air contaminants by:

1) ***Diluting contaminants with outdoor air***
   a. Increase the total quantity of supply air (including outdoor air)
   b. Increase the proportion of outdoor air to total air
   c. Improve air distribution
2) ***Isolating or removing contaminants by controlling air pressure relationships***
   a. Install effective local exhaust at the location of the source
   b. Avoid recirculation of air that contains contaminants
   c. Locate occupants near supply diffusers and sources near exhaust registers
   d. Use air-tightening techniques to maintain pressure differentials and eliminate pollutant pathways
   e. Make sure that doors are closed where necessary to separate zones

Diluting contaminants with outdoor air

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

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

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

Most ventilation deficiencies appear to be linked to inadequate quantities of outdoor air. However, inadequate distribution of ventilation air can also produce IAQ problems. Diffusers should be properly selected, located, installed, and maintained so that supply air is evenly distributed and blends thoroughly with room air in the breathing zone. Short-circuiting occurs when clean supply air is drawn into the return air plenum before it has mixed with the dirtier room air and therefore fails to dilute contaminants.

Mixing problems can be aggravated by temperature stratification. Stratification can occur, for example, in a space with high ceilings in which ceiling-mounted supply diffusers distribute heated air.

Note the side effects of increased ventilation:

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

The designer may wish to give consideration to the conditioning of indoor air with odour removing equipment as an alternative to ventilation with outdoor air. This can take a number of forms, the one most widely applied to building air conditioning being adsorption by activated charcoal. This material is supplied in pellet form and applied as a bed through which the air stream passes. Performance can be varied through the design of the bed and the selection of the material. When the charcoal has adsorbed its full capacity of odorants, it is usually returned to the manufacturer for regeneration and replaced with fresh charcoal. The design of such a system would normally be based on established requirements for outdoor air. For example, if outdoor air requirements for odour control amount to 20 per cent of the air being circulated, processing all of the circulating indoor air with an odour controlling device that is 20 per cent effective would give comparable results. Outdoor air would, however, normally be required in sufficient quantity to maintain CO_2 levels within acceptable limits. In unusual situations where outdoor air is not available, such as in submarines, the CO_2 levels can be controlled by chemical treatment.

Note: Because of the high ventilation rates, the cost of conditioning outdoor air goes up significantly. Increasing a building's ventilation rate to speed up the removal of localized air-borne contaminants, even when energy use is not a concern, is not a solution to every problem. The most efficient strategy to improve air quality is to remove the contaminants at the source by local exhaust and then to rely on ventilation for the rest of the building. In the case of an identifiable contaminant source such as office equipment, the exhaust from the source should be connected directly to the outside.

Isolating or removing contaminants by controlling air pressure relationships

A variety of airborne particles, such as dust, smoke, pollens and organisms are contained in the outdoor air and are brought indoors along with the ventilation air. Lot of contaminants are generated indoors by the activities of the occupants. *If the contaminant source has been identified, the "Isolation or Removal" can be more effective than "Dilution".*

The term *"ventilation efficiency*" is used to describe the ability of the ventilation system to distribute supply air and remove internally generated pollutants. Researchers are currently studying ways to measure ventilation efficiency and interpret the results of those measurements.

Limiting the concentrations of contaminants could use any of the following techniques depending on the nature and severity of the contaminant:

1) The first technique for isolating odours and contaminants is to design and operate the HVAC system so that pressure relationships between rooms are controlled. This control is accomplished by adjusting the air quantities that are supplied to and removed from each room.

   If more air is supplied to a room than is exhausted, the excess air leaks out of the space and the room is said to be under *positive pressure*. If less air is supplied than is exhausted, air is pulled into the space and the room is said to be under *negative pressure*.

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

2) The second technique is to use local exhaust systems (sometimes known as dedicated exhaust ventilation systems) to isolate and remove contaminants by maintaining negative pressure in the area around the contaminant source. It also dilutes the contaminant by drawing cleaner air from surrounding areas into the exhaust airstream.

   Local exhaust can be linked to the operation of a particular piece of equipment (such as a kitchen range) or used to treat an entire room (such as a smoking lounge or custodial closet). Air should be exhausted to the outdoors, not recirculated, from locations which produce significant odours and high concentrations of contaminants (such as copy rooms, bathrooms, kitchens, and beauty salons).

   Spaces where local exhaust is used must be provided with make-up air and the local exhaust must function in coordination with the rest of the ventilation system. Under some circumstances, it may be acceptable to transfer conditioned air from relatively clean parts of a building to comparatively dirty areas and use it as make-up air for a local exhaust system. It may be necessary to add door or wall louvers in order to provide a path for the make-up air. (Make sure that this action does not violate fire codes.)

   Such a transfer can achieve significant energy savings.

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

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

3) The third technique is to use HVAC designs that introduce 100% outdoor air or that simply transfer air within the building. In hospitals for instance, where the control of infection from airborne sources is of special importance, ventilation is used to provide positive pressures in spaces containing patients prone to infection and negative pressures in spaces containing patients with highly communicable diseases. It is common practice also to circulate a high proportion of outdoor air, up to 100 per cent, in areas such as operating rooms. This results in a particularly high heating and cooling load for ventilation and leads designers to consider the economics of heat recovery devices in the exhaust air

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Air Cleaning

The third IAQ control strategy is to clean the air. Air cleaning is usually most effective when used in conjunction with either source control or ventilation; however, it may be the only approach when the source of pollution is outside of the building.

Most air cleaning in large buildings is aimed primarily at preventing contaminant buildup in HVAC equipment and enhancing equipment efficiency.

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

There are four technologies that remove contaminants from the air:

1) Particulate filtration
2) Electrostatic precipitation
3) Negative ion generation
4) Gas sorption

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

Particulate filtration:

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

Electrostatic Precipitation:

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

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

Negative ion generators:

Negative ion generators use static charges to remove particles from the indoor air. When the particles become charged, they are attracted to surfaces such as walls, floors, table tops, draperies, and occupants.

Some designs include collectors to attract the charged particles back to the unit.

Negative ion generators are not available for installation in ductwork, but are sold as portable or ceiling-mounted units. As with electrostatic precipitators, negative ion generators may produce ozone, either intentionally or as a by-product of use.

Gas sorption:

Gas sorption is used to control compounds that behave as gases rather than as particles (e.g., gaseous contaminants such as formaldehyde, sulfur dioxide, ozone, and oxides of nitrogen). Gas sorption involves one or more of the following processes with the sorption material (e.g., activated carbon, chemically treated active clays):

A chemical reaction between the pollutant and the sorbent, a binding of the pollutant and the sorbent, or diffusion of the contaminant from areas of higher concentration to areas of lower concentration. Gas sorption units are installed as part of the air distribution system. Each type of sorption material performs differently with different gases. Gas sorption is not effective for removing carbon monoxide. There are no standards for rating the performance of gaseous air cleaners, making the design and evaluation of such systems problematic.

Operating expenses of these units can be quite high, and the units may not be effective if there is a strong source nearby.

HVAC Controls

HVAC controls allow the system to run smoothly according to the acceptable IAQ ventilation strategy and in response to the changing indoor and outdoor environments. This seems obvious, since no other single issue affects IAQ more than supplying an adequate amount of outside air to a building for ventilation. Regardless of the type of automatic control system in the facilities, these principles can be applied.

Interlock the outside air dampers with the air-handling unit:

In hot and humid climates, elevated RH can result if the automatic outside air dampers are not properly interlocked.

In cold winter climates, the improper control of outside air dampers can lead to coils freezing up and result in water damage, which could eventually lead to microbial growth and IAQ problems. Automatic outside air dampers should be opened to the minimum outside air position whenever the air-handling unit (AHU) is serving an occupied space.

For simple control systems, the automatic outside air dampers can be easily interlocked with the AHU motor starter to close when the AHU is off. In a more complex control system with direct digital control (DDC) having more advanced capabilities, a separate time schedule should be set up and programmed for the outside air dampers to be closed whenever the space is unoccupied.

Use carbon dioxide sensors for demand control ventilation:

Carbon dioxide-based demand- controlled ventilation systems vary the ventilation rate based on carbon dioxide (CO_2) levels in the building. For spaces with extreme variations in occupancy, such as banquet halls or meeting rooms, carbon dioxide sensors located in each zone adjacent to the room thermostat or in the common return air automatically control the amount of outside air. The controls are set such that the CO_2 level do not exceed ASHRAE permissible levels of 1000ppm.

The equation for calculating outdoor quantities using carbon dioxide measurements is:

$$\text{Outdoor air (in percent)} = \frac{C_s - C_r}{C_0 - C_r} \times 100$$

Where:
Cs= ppm of carbon dioxide in the mixed air (if measured at an air handler) or in supply air (if measured in a room)
Cr= ppm of carbon dioxide in the return air
Co= ppm of carbon dioxide in the outdoor air

The auto-controller ensures that the increased ventilation is supplied only when required or needed for higher occupancies. This benefit in the energy cost savings because of reduced cooling and heating of outdoor air during reduced occupancy rates.

Use outside airflow stations on large systems to monitor the ventilation rate:

For critical areas or large central air-handling systems (50,000 CFM or more), airflow-monitoring stations can to provide outside airflow measurement and indication at a local panel or remotely at the workstation. Not only can the real-time outside airflow rate be measured accurately, but the outside airflow rate can be scheduled and controlled accurately to meet a predetermined ventilation rate for a certain period if the number of occupants for an event is known or based on CO_2 levels.

Control of Relative Humidity:

The amount of moisture is controlled by the amount of cooling (air conditioning & dehumidification). If the building is located in high hot and humid climates, then more air conditioning is needed to condense the water out of the air and provide cooler, dryer air. If cooling is inadequate the probability of having mold grow in the building is greater.

In comfort air-conditioning system normally the temperature control takes precedence over the humidity control. *The RH can swing drastically when negative pressure is present, when a large amount of outside air is being supplied through the unit, or during light load conditions.*

The easiest and most cost-effective methods of bringing humidity under control for constant air volume systems during light load conditions is to install room humidity controls to override the cooling system when the RH exceeds 60%. A humidistat can be installed parallel with thermostat cooling control and functions to override the cooling signal from a thermostat. This means that humidity control will take precedence over temperature control during light load conditions and the sub-cooled air shall be reheated to the thermostat setpoint as a second step. An energy efficient way of accomplishing this is to consider the variable air volume system.

Note that this strategy should be applied only after ensuring building air tightness and eliminating negative pressure areas. Excessive infiltration must be plugged, otherwise, the result will be increased utility costs and shorter expected life for the air conditioning equipment from excessive runtimes. Energy codes in some states, such as Florida, have restricted the use of electric reheat for humidity control below 60% RH.

Use variable-air volume (VAV) cooling systems with minimum outdoor air intake:

VAV systems inherently provide improved control of RH over constant volume, variable temperature systems since the leaving air temperature is controlled at a fixed temperature. The RH can be controlled by adjusting the supply air temperature to achieve the desired dewpoint temperature in the space. The cooling capacity of a VAV system is regulated by varying the volume of the cold supply air to each room. VAV terminals for each zone can be provided with or without reheat coils.

One of the biggest disadvantages of VAV system is that with reduced supply flow rates the decreasing amount of outdoor air was provided. This problem is very common in the early designs. Most early VAV systems did not allow control of the outdoor air quantity, so that a decreasing amount of outdoor air was provided as the flow of supply air was reduced. Some more recent designs ensure a minimum supply of outdoor air with static pressure devices in the outdoor air stream. Make sure the HVAC system is interlocked to ensure minimum outdoor air intake.

Precondition the outside air supplied to corridors:

The 100% outside air systems used to pressurize and transfer air within the building should be pre-conditioned particularly to remove moisture from the air. Hotel rooms for instance are provided with such system. The 100% outside conditioned air is used primarily to pressurize the corridor and room which is generally equipped with fan coil recirculation units to meet primarily the sensible load requirements of the room.

Interlock exhaust fans with the outside air dampers:

Make sure that all exhaust fans are interlocked properly with the associated AHU's wherever possible. This will ensure that the exhaust fans operate only when the associated AHU is running or when the outside air dampers are open during occupied periods. This requires the design engineer to zone the AHU's and exhaust fans to work together, or this may not be possible to achieve when occupancy schedules between zones are significantly different.

HVAC Operation & Maintenance Checklist

Air Handling Units (AHU's):

1. Locate air intakes away from pollutant sources – exhausts, drains, standing water, garbage compactors, loading docks, bus stops, bird roosts, water towers, condensers, etc.
2. Ensure that a screen covers the outdoor air intake to capture debris – leaves, papers, etc.
3. Stagnant water should not be present within the mechanical system. Drain rain/snow in the outdoor air intake.
4. Ensure that interior acoustic/thermal insulation is not porous, and is cleanable. Exposed fiberglass should be covered and all seams sealed. Protect insulated floors that will be walked on.
5. Ensure that the outdoor air damper controls are functioning and at the minimum ventilation rate, dampers should not be completely closed.

6. Access should be provided to all system components for routine inspection and maintenance. Access doors or panels should be sealed to prevent air leakage.

Filters:

1. Distance the filter bank from the outdoor air intake so that it cannot be wetted by rain/snow.
2. Position the filters after the return air mixing plenum and before system components.
3. Have a well racked filter system with no air by-pass.
4. Maximize filtration performance. Small systems, due to space limitations should use pleated filters with a minimum dust-spot efficiency of 30 %. Larger AHUs should have roll, panel, or pleated pre-filters and 85 % efficiency [or greater] pleated or bag filters.
5. Electronic filters are also an option as a secondary filter. The prefilter will collect larger size particles. Electronic filters work best at air flow velocities from 150 to 350 feet per minute.
6. A pressure drop indicator should be installed across the filter bank; a differential pressure gauge is easier to use and calibrate than an inclined manometer.

Humidification Systems:

1. Steam systems require less maintenance than water-spray units and have less potential for microbial contamination. Wetted media humidifiers are applicable for warm dry climates; periodic maintenance and water treatment are required.
2. Steam humidifiers should have a dedicated boiler or steam generator that supplies clean steam, or use a steam-to-steam converter. Hot water and heating system boilers use chemically treated water to inhibit corrosion and these chemicals, which include amines, can become airborne if this steam is used for humidification.
3. Maintain relative humidity according to the ASHRAE thermal comfort range [ASHRAE 55-1992], between 25 - 60 % during occupied periods, 70 % maximum during unoccupied periods. [Usually air is humidified to between 25-45 % during the winter and dehumidified to below 60 % during the summer].
4. Total evaporation within the humidification system enclosure is required. Moisture should not pass through into the fan enclosure or into the supply ductwork. Water systems may require drift-eliminators. Wet interior system walls and insulation must be avoided.
5. Reservoirs and condensate pans must be able to drain properly and trap depth and height differential between the inlet and outlet must be designed to overcome the system static pressure [positive or negative]. This is especially critical if the fan is run 24 hours a day. Traps with a continuous water bleed, will also eliminate the reverse flow of sewer gas.

Cooling/Heating Coils:

1. Ensure access to both sides of all coils for cleaning.
2. Condensate pans should not be insulated on the inside [interior perimeter and ceiling fan coil units included], and should be sloped to a drain. Avoid stagnant water.
3. Individual finned-tube coils should be no deeper than 8 rows to facilitate cleaning.

Fans:

1. Fans should be sized and located so that no moisture is pulled through into the fan enclosure and adjacent ducts.
2. The system should be designed for compliance with the ASHRAE ventilation standard [62-1999] and also have a fan performance capability of providing the recommended air changes per hour [ACH]. For an office building this usually ranges between 4 to 6 ACH, resulting in a circulation rate of between 0.7 to 1 cubic foot per minute per square foot of floor area.

3. The building's interior should be under a slight positive pressure [10 % more supply than exhaust, or between 0.025 to 0.05 inch water gauge] so as to operate under controlled exfiltration, rather than uncontrolled infiltration with unconditioned outside air.
4. Pressure relationships should be used to control air flow between interior zones; air should flow from clean to less clean areas. For example, office areas towards washrooms, labs, printing facilities, loading docks, etc.
5. Stack effect in buildings, where hot air rises, can have negative effects on IAQ [temperature differences, uncontrolled interior pressure differentials, reduced ventilation]. The building and system design should be able to counterbalance this effect.

Interior Space:

1. Supply diffusers should be located away from return slots to prevent short-circuiting.
2. Diffuser design should incorporate an effective means of delivering air to the occupants in the workplace, considering office design and layout.
3. Pollutant source control is more effective than dilution by ventilation. Position contaminant-generating equipment under returns; place in enclosed areas. Remove strong contaminants at the source using separate exhaust.
4. Building envelope assemblies; walls, roof and glass, must have proper insulation coefficients to avoid surface condensation at maximum relative humidity conditions. Missing or reduced insulation will produce a cold spot [thermal bridge] where condensation may form.
5. An integral building envelope vapor barrier is necessary in order to avoid moisture infiltration and migration, from both inside and outside the building.
6. It is not good practice to use unbonded fiberglass as acoustic insulation in the ceiling return air plenum. Not only is this not effective, but fibers will migrate to the workplace.
7. Thermostats should control areas having similar thermal requirements. The perimeter zone of an office will have different needs than the interior. Each side of a building will have different solar gains and radiant heat transfer.

Commissioning & Balancing:

New buildings require proper system design and commissioning to achieve good IAQ. This process confirms that the buildings systems perform as intended, are tested adjusted and balanced (TAB) and that documentation, training and an operation and maintenance plan are complete.

If the heating/cooling system is not properly balanced, it is very possible for building areas to be under negative pressure anytime the HVAC fan is running. This significantly impacts the indoor air quality as it allows for the entry of fine particles and gases from the outside to be pulled into the occupied environment.

The provision of good IAQ for new and renovated buildings is dependent on both proper systems design and a comprehensive commissioning process. The following procedures should be incorporated:

1. During construction periods where quantities of dust are generated, the return system should be blocked off and the HVAC system should be protected from contamination. Do not operate the HVAC system without filters. Prior to occupancy, replace the pre-filters.
2. During fit-up, run the system 24 hours a day to ventilate the off-gassing of VOCs from carpets, wall coverings, furnishings, equipment, window blinds, etc. The system may need to be run continuously several weeks after occupancy, depending on whether odors are still present. During this time, maximum outside air [ventilation] should also be provided.
3. Establish a communication channel between the occupants and the building manager/operator. Areas may have to be fine-tuned.

The importance of the commissioning process for good IAQ must be emphasized. ASHRAE guideline, 1-1999, focuses on the mechanical system performance and operation. Starting with a system that works, that is balanced with respect to occupancy and equipment requirements, where the operators are trained and procedures are documented, and where the IAQ is in compliance with good practice is the right of all building occupants.

Operation & Maintenance:

Air supplied to the occupied space passes through a series of central and terminal mechanical systems and components ; outside air is mixed with return air, filtered, cooled or heated, humidified or dehumidified, and transported through ducts, dampers and other additional air conditioning systems (induction units, fan-coil units, variable air volume boxes, etc). Each component in this chain has to be regularly and properly maintained to perform as intended so that healthy and comfortable conditions are provided in the workplace.

Although buildings and systems vary in complexity, there are certain generally accepted rules and good engineering practices with regard to system operation and maintenance.

O & M guidelines in the mechanical room:

1. Inspect the HVAC system components monthly; outdoor air intake, screen, dampers, mixing plenum, filters, humidifier, coils, fan, etc. Clean and repair if necessary.
2. Schedule routine maintenance according to the O&M manual
3. Water spray humidifier reservoirs and cooling coil condensate pans should be cleaned monthly; during down-time, drain, brush with a bleach solution, and rinse.
4. If the mechanical room serves as a return plenum, do not store or mix chemicals in this area.
5. Replace pre-filters and secondary filters according to specified pressure drop [pre- filters are usually replaced several times a year and secondary filters are replaced after 12 to 18 months]. Change filters that have become wet.
6. Visually inspect covered or non-porous internal and external acoustic and thermal insulation for dirt build-up, tears, and mould growth. Clean dirty surfaces using a HEPA filtered vacuum, seal broken surfaces and remediate the mould problem.
7. The use of encapsulants and biocides, sprayed on internally insulated ducts to control microbial growth, is not recommended. Keep surfaces dry and clean; discard porous materials that are contaminated.
8. Do not allow condensate to form on cold pipes and ducts; these should be insulated. Valves, gauges, regulators, etc. should not drip on porous material to avoid damage and microbial growth.
9. Monitor water quality in reservoirs, water towers, evaporative condensers, etc. on a regular basis for bacteria (Legionella) and other bioaerosols. While chemical treatment for water towers is usually required, it is imperative that vapors or mists from the treated water not be re-entrained into the outdoor air intake. Monitor the rate of "blow-down" and it is usual to limit the "cycles of concentration" to less than five.
10. Pollutant source control is a far better, cost effective option for good IAQ than increasing the ventilation rate. Adding more outside air simply dilutes levels of indoor contaminants. The HVAC system itself may be a source of contamination; microbial amplification site, unbonded fiberglass, outdoor pollutant entrainment, etc.
11. It is prudent to keep a log of maintenance activities, incidents, and records of occupant's complaints and how the issue was resolved.

O & M guidelines in the occupied space:

1. Inadequate housekeeping may cause IAQ problems. Dirty fleecy materials; carpets, partitions, chairs, may harbor allergenic particulates such as dust, spores, dander, mites, etc. Using a high performance, multi-filtered vacuum will collect more dirt and re- exhaust less airborne particles.
2. The air delivery system should be rebalanced to reflect changes in occupancy, activity, or layout. The air supply in existing zones should be verified every five years.

3. The use of certain waxes, glues, paints, caulking, pesticides, etc., can have a negative effect on IAQ and building occupants. Often the impact can be minimized by proper product selection, time of use, ventilation, confinement, and last but not least, communication.
4. Where possible, schedule office refits (new carpets, painting, new furnishings, etc.) during the spring or fall season when the ventilation rate can be maximized (free- cooling, economizer cycle).
5. Wetted interior surfaces; walls, carpets, ceilings, require prompt remedial action. First, find and correct the cause, then dry, clean or replace the penetrated area.
6. When renovating a section, isolate the work area to confine contaminants. This area should be placed under negative pressure and the returns should be blocked to prevent pollutants being recirculated within the entire building.

Duct Cleaning:

With regard to air supply duct cleaning, both EPA [1991] and SMACNA [1998], provides good advice in determining the need for cleaning. Basically, the amount of dust and particulates within the duct depends on many factors such as the age of the building, the filtration efficiency, past construction and refit cleanup practices, level of system maintenance and housekeeping, etc. It is important to have visual access to ducts to assess their condition. While some amount of surface dust does not indicate a problem [or a reduction in air flow or system pressure], duct interiors that have damaged liners, loose fibreglass insulation, or are wet or have microbial growth, require remediation. Often, the return systems are dirtier than the supply. Central, terminal and perimeter air handling systems require routine maintenance and cleaning. Efforts to establish duct cleaning standards and guidelines are currently being investigated by various authorities.

EXPOSURE CONTROL

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

1) ***Scheduling contaminant-producing activities to avoid complaints***

   a. Schedule contaminant-producing activities to occur during unoccupied periods

   b. Notify susceptible individuals about upcoming events (e.g., roofing, pesticide application) so that they can avoid contact with the contaminants

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

2) ***Relocating susceptible individuals***

   a. Move susceptible individuals away from the area where they experience symptoms

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

Section- 3 SAMPLE PROBLEMS AND SOLUTIONS

This section presents fifteen categories of IAQ problems.

Specific problem “examples” are given, followed by solutions” that have been used for that category of problem.

Most of the problems presented here are common and do not have serious, life threatening consequences. At the end of the section is a brief description of problems that can have severe health impacts. The basic correction principles that apply to these serious problems are similar to those used in less critical situations.

Reading these examples may help you to think about the best way to solve your indoor air quality problems. Remember that these are brief sketches, and apparent parallels to your building could be misleading.

It is better to carry out a building investigation and learn the specific facts in your own case, rather than adopt a mitigation approach that might not be appropriate.

Attempting to correct IAQ problems without understanding the cause of those problems can be both ineffective and expensive.

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

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

Problem #1: Outdoor air ventilation rate is too low

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

Problem #3: Contaminant enters building from outdoors

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

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

Problem #6: HVAC system distributes contaminants

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

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

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

Problem #10: Building materials and furnishings produce contaminants

Problem #11: Housekeeping or maintenance activities contribute to problems

Problem #12: Specialized use areas as sources of contaminants

Problem #13: Remodeling or repair activities produce problems

Problem #14: Combustion gases

Problem #15: Serious building-related illness

Problem #1:

Outdoor Air Ventilation Rate is too Low

Examples

1) Routine odors from occupants and normal office activities result in problems (e.g., drowsiness, headaches, discomfort)
2) Measured outdoor air ventilation rates do not meet guidelines for outdoor air supply (e.g., design specifications, applicable codes, or ASHRAE 62-1989)

3) Peak CO_2 concentrations above 1000 ppm indicate inadequate ventilation
4) Corrosion of fan casing causes air bypassing and reduces airflow in system

Solutions

1) Open, adjust or repair air distribution system
   a. Outdoor air intakes
   b. Mixing and relief dampers
   c. Supply diffusers
   d. Fan casings
2) Increase outdoor air within the design capacity of
   a. Air handler
   b. Heating and air conditioning equipment
   c. Distribution system
3) Modify components of the HVAC system as needed to allow increased outdoor air (e.g., increase capacity of heating and cooling coils)
4) Design and install an updated ventilation system
5) Reduce the pollutant and/or thermal load on the HVAC system
   a. Reduce the occupant density: relocate some occupants to other spaces to redistribute the load on the ventilation system
   b. Relocate or reduce usage of heat generating equipment

Problem #2:

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

Examples

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

Solutions

1) Open, adjust, or repair air distribution system
   a. Supply diffusers
   b. Return registers
2) Ensure proper air distribution
   a. Balance the air handling system
   b. Make sure that there is an air gap at tops and bottoms of partitions to prevent dead air space
   c. Relocate supply and/or return diffusers to improve air distribution
3) Seal leaky ductwork Remove obstructions from return air plenum
4) Control pressure relationships
   a. Install local exhaust in problem areas and adjust HVAC system to provide adequate make-up air
   b. Move occupants so that they are closer to supply diffusers
   c. Relocate identified contaminant sources closer to exhaust intakes

5) Reduce source by limiting activities or equipment use that produce heat, odours, or contaminants
6) Design and install an appropriate ventilation system

Problem #3:

Contaminant Entering Building from Outdoors

Examples

1) Soil gases (e.g., radon, gasoline from tanks, methane from landfills)
2) Contaminants from nearby activities (e.g., roofing, dumpster, construction)
3) Outdoor air intake near source (e.g., parking, loading dock, building exhaust)
4) Outdoor air contains pollutants or excess moisture (e.g., cooling tower mist entrained in outdoor air intake)

Solutions

1) Remove the source, if it can be moved easily
   a. Remove debris around outdoor air intake
   b. Relocate dumpster
2) Reduce source (for example, shift time of activity to avoid occupied periods)
   a. Painting, roofing, demolition
   b. Housekeeping, pest control
3) Relocate elements of the ventilation system that contribute to entry of outdoor air contaminants
   a. Separate outdoor air intakes from sources of odours, contaminants
   b. Separate exhaust fan outlets from operable windows, doors, air intakes
   c. Make rooftop exhaust outlets taller than intakes
4) Change air pressure relationships to control pollutant pathways
   a. Install sub-slab depressurization to prevent entry of soil gas contaminants (radon, gases from landfills and underground tanks)
   b. Pressurize the building interior relative to outdoors (this will not prevent contaminant entry at outdoor air intakes)
   c. Close pollutant pathways (e.g., seal cracks and holes)
5) Add special equipment to HVAC system
   a. Filtration equipment to remove pollutants (select to fit the situation)

Problem #4:

Occupant Activities Contribute to Air Contaminants or to Comfort Problems

Examples

1) Smoking
2) Special activities such as print shops, laboratories, kitchens
3) Interference with HVAC system operation:
   a. Blockage of supply diffusers to eliminate drafts
   b. Turning off exhaust fans to eliminate noise
   c. Use of space heaters, desktop humidifiers to remedy local discomfort

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

Solutions

1) Remove the source by eliminating the activity

(Note: This may require a combination of policy-setting and educational outreach.)

   a. Smoking
   b. Use of desktop humidifiers and other personal HVAC equipment
   c. Unsupervised manipulation of HVAC system

2) Reduce the source
   a. Select materials and processes which minimize release of contaminants while maintaining adequate safety and efficacy (e.g., solvents, art materials)

3) Install new or improved local exhaust to accommodate the activity, adjust HVAC system to ensure adequate make-up air, and verify effectiveness
   a. Smoking lounge, storage areas which contain contaminant sources
   b. Laboratory hoods, kitchen range hoods (venting to outdoors, not recirculating)

Problem #5:

HVAC System is a Source of Biological Contaminants

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

Examples

1) Surface contamination by molds (fungi), bacteria
   a. Drain pans
   b. Interior of ductwork
   c. Air filters and filter media (collected debris).

Solutions

1) Remove source by improving maintenance procedures
   a. Inspect equipment for signs of corrosion, high humidity
   b. Replace corroded parts clean drip pans, outdoor air intakes, other affected locations
   c. Use biocides, disinfectants, and sanitizers with extreme caution and ensure that occupant exposure is minimized

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

Problem #6:

HVAC System Distributes Contaminants

Examples

1) Unfiltered air bypasses filters due to problems
   a. Filter tracks are loose
   b. Poorly-maintained filters sag when they become overloaded with dirt
   c. Filters are the wrong size

2) Recirculation of air that contains dust or other contaminants

a. System recirculates air from rooms containing pollutant sources

b. Return air plenum draws air from rooms that should be exhausted (e.g. janitor's closets)

c. Return air plenums draw soil gases from interiors of block corridor walls that terminate above ceilings

Solutions

1) Modify air distribution system to minimize recirculation of contaminants

   a. Provide local exhaust at point sources of contaminants, adjust HVAC system to provide adequate make-up air, and test to verify performance

   b. Increase proportion of outdoor air

   c. Seal unplanned openings into return air plenums and provide alternative local ventilation (adjust HVAC system to provide adequate make-up air and test to verify performance)

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

3) Install improved filtration equipment to remove contaminants

4) Check filter tracks for any gaps

Problem #7:

Non-HVAC Equipment is a Source or Distribution Mechanism for Contaminants

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

Examples

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

   a. Wet process copiers

   b. Large dry process copiers

   c. Engineering drawing reproduction machines

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

   a. Elevators, which can act as pistons and draw contaminants from one floor to another

Solutions

1) Install local exhaust near machines

   (Note: Adjust HVAC system to provide adequate make-up air, and test to verify performance.)

2) Reschedule use to occur during periods of low occupancy

3) Remove source

   a. Relocate occupants out of rooms that contain contaminant-generating equipment

   b. Relocate equipment into special use areas equipped with effective exhaust ventilation (test to verify control of air pressure relationships)

4) Change air pressure relationships to prevent contaminants from entering elevator shaft

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Problem #8:

Surface Contamination Due to Poor Sanitation or Accidents

Examples

1) Biological contaminants result in allergies or other diseases

   a. Fungal, viral, bacterial (whole organisms or spores)

   b. Bird, insect, or rodent parts or droppings, hair, dander (in HVAC, crawlspace, building shell, or near outdoor air intakes)

2) Accidents

   a. Spills of water, beverages, cleansers, paints, varnishes, mastics or specialized products (printing, chemical art supplies)

   b. Fire damage: soot, odours, chemicals

Solutions

1) Clean

   a. HVAC system components

   b. Some materials and furnishings (others may have to be discarded)

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

2) Remove sources of microbiological contamination

   a. Water-damaged carpet, furnishings, or building materials

3) Modify environment to prevent recurrence of microbiological growth

   a. Improve HVAC system maintenance

   b. Control humidity or surface temperatures to prevent condensation

4) Provide access to all items that require periodic maintenance

5) Use local exhaust where corrosive materials are stored

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

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Problem #9:

Mold and Mildew Growth Due to Moisture from Condensation

Examples

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

2) Carpeting on cold floors

3) Locations where high surface humidity promotes condensation

Solutions

1) Clean and disinfect to remove mold and mildew.

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

2) Increase surface temperatures to treat locations that are subject to condensation

   a. Insulate thermal bridges

   b. Improve air distribution

3) Reduce moisture levels in locations that are subject to condensation

   a. Repair leaks

   b. Increase ventilation (in cases where outdoor air is cold and dry)

   c. Dehumidify (in cases where outdoor air is warm and humid)

4) Dry carpet or other textiles promptly after steam cleaning

   (Note: Increase ventilation to accelerate drying.)

5) Discard contaminated materials

Problem #10:

Building Materials and Furnishings Produce Contaminants

Examples

1) Odours from newly installed carpets, furniture, wall coverings
2) Newly dry cleaned drapes or other textiles

Solutions

1) Remove source with appropriate cleaning methods
    a. Steam clean carpeting and upholstery, then dry quickly, ventilating to accelerate the drying process
    b. Accept only fully dried, odourless dry cleaned products
2) Encapsulate source
    a. Seal surfaces of building materials that emit formaldehyde
3) Reduce source
    a. Schedule installation of carpet, furniture, and wall coverings to occur during periods when the building is unoccupied
    b. Have supplier store new furnishings in a clean, dry, well-ventilated area until VOC out gassing has diminished
4) Increase outdoor air ventilation
    a. Total air supplied
    b. Proportion of fresh air
5) Remove the materials that are producing the emissions and replace with lower emission alternatives

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Problem #11:

Housekeeping or Maintenance Activities Contribute to Problems

Examples

1) Cleaning products emit chemicals, odours
2) Particulates become airborne during cleaning (e.g., sweeping, vacuuming)
3) Contaminants are released from painting, caulking, lubricating
4) Frequency of maintenance is insufficient to eliminate contaminants

Solutions

1) Remove source by modifying standard procedures or frequency of maintenance

(Note: Changing procedures may require a combination of policy-setting and training in IAQ impacts of staff activities.)

  a. Improve storage practices
  b. Shift time of painting, cleaning, pest control, other contaminant-producing activities to avoid occupied periods
  c. Make maintenance easier by improving access to filters, coils, and other components

2) Reduce source

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

3) Use local exhaust
   a. On a temporary basis to remove contaminants from work areas
   b. As a permanent installation where contaminants are stored

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Problem #12:

Specialized Use Areas as Sources of Contaminants

Examples

1) Food preparation
2) Art or print rooms
3) Laboratories

Solutions

1) Change pollutant pathway relationships
   a. Run specialized use area under negative pressure relative to surrounding areas
   b. Install local exhaust, adjust HVAC system to provide make-up air, and test to verify performance
2) Remove source by ceasing, relocating, or rescheduling incompatible activities
3) Reduce source by selecting materials to minimize emissions of contaminants while maintaining adequate safety and efficacy
4) Reduce source by using proper sealing and storage for materials that emit contaminants

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Problem #13:

Remodeling or Repair Activities Produce Problems

Examples

1) Temporary activities produce odours and contaminants
   a. Installation of new particleboard, partitions, carpet, or furnishings
   b. Painting
   c. Roofing
   d. Demolition
2) Existing HVAC system does not provide adequate ventilation for new occupancy or arrangement of space

Solutions

1) Modify ventilation to prevent recirculation of contaminants
   a. Install temporary local exhaust in work area, adjust HVAC system to provide make-up air, and test to verify performance
   b. Seal off returns in work area
   c. Close outdoor air damper during re-roofing
2) Reduce source by scheduling work for unoccupied periods and keeping ventilation system in operation to remove odours and contaminants

3) Reduce source by careful materials selection and installation
    a. Select materials to minimize emissions of contaminants while maintaining adequate safety and efficacy
    b. Have supplier store new furnishings in a clean, dry, well-ventilated area until VOC out gassing has diminished
    c. Request installation procedures (e.g., adhesives) that limit emissions of contaminants
4) Modify HVAC or wall partition layout if necessary
    a. Partitions should not interrupt airflow
    b. Relocate supply and return diffusers
    c. Adjust supply and return air quantities
    d. Adjust total air and/or outdoor air supply to serve new occupancy

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Problem #14:

Combustion Gases

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

Examples

1) Vehicle exhaust
    a. Offices above (or connected to) an underground parking garage
    b. Rooms near (or connected by pathways to) a loading dock or service garage
2) Combustion gases from equipment
    a. For e.g., spillage from inadequately vented appliances, cracked heat exchanger, re-entrainment because local chimney is too low
    b. Areas near a mechanical room
    c. Distributed throughout zone or entire building

Solutions

1) Seal to remove pollutant pathway
    a. Close openings between the contaminant source and the occupied space
    b. Install well-sealed doors with automatic closers between the contaminant source and the occupied space
2) Remove source
    a. Improve maintenance of combustion equipment
    b. Modify venting or HVAC system to prevent backdrafting
    c. Relocate holding area for vehicles at loading dock, parking area
    d. Turn off engines of vehicles that are waiting to be unloaded
3) Modify ventilation system
    a. Install local exhaust in underground parking garage (adjust HVAC system to provide make-up air and test to verify performance)
    b. Relocate fresh air intake (move away from source of contaminants)
4) Modify pressure relationships
    a. Pressurize spaces around area containing source of combustion gases

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Problem #15:

Serious Building-Related Illness

Some building-related illnesses can be life threatening.

Even a single confirmed diagnosis (which involves results from specific medical tests) should provoke an immediate and vigorous response.

Examples

1) Legionnaire's disease
2) Hypersensitivity pneumonitis

Solutions

1) Work with public health authorities
   a. Evacuation may be recommended or required
2) Remove source
   a. Drain, clean, and decontaminate drip pans, cooling towers, room unit air conditioners, humidifiers, dehumidifiers, and other habitats of Legionella, fungi, and other organisms using appropriate protective equipment install drip pans that drain properly
   b. Provide access to all the items that must be cleaned, drained, or replaced periodically
   c. Modify schedule and procedures for improved maintenance
3) Discontinue processes that deposit potentially contaminated moisture in air distribution system
   a. Air washing
   b. Humidification
   c. Cease nighttime shutdown of air handlers

JUDGING PROPOSED MITIGATION DESIGNS AND THEIR SUCESS

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

1. Permanence
2. Operating principle
3. Degree to which the strategy fits the job
4. Ability to institutionalize the solution
5. Durability
6. Installation and operating costs
7. Conformity with codes

Permanence

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

Operating Principle

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

Degree to Which the Strategy Fits the Job

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

If mechanical equipment is needed to correct the IAQ problem, it must be powerful enough to accomplish the task.

For example, a local exhaust system should be strong enough and close enough to the source so that none of the contaminant is drawn into nearby returns and recirculated.

Ability to Institutionalize the Solution

A mitigation strategy will be most successful when it is institutionalized as part of normal building operations. Solutions that do not require exotic equipment are more likely to be successful in the long run than approaches that involve unfamiliar concepts or delicately maintained systems.

If maintenance or housekeeping procedures or supplies must change as part of the mitigation, it may be necessary to plan for additional staff training, new inspection checklists, or modified purchasing practices.

Operating schedules for HVAC equipment may also require modification.

Durability

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

Installation and Operating Costs

The approach with the lowest initial cost may not be the least expensive over the long run. Other economic considerations include: energy costs for equipment operation, increased staff time for maintenance; differential cost of alternative materials and supplies; and higher hourly rates if odour-producing activities (e.g., cleaning) must be scheduled for unoccupied periods.

Although these costs will almost certainly be less than the costs of letting the problem continue, they are more readily identifiable, so an appropriate presentation to management may be required.

Conformity with Codes

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

JUDGING SUCCESS OF A MITIGATION EFFORT

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

1. reduced complaints

2. measurement of properties of the indoor air (often only of limited usefulness)

Reduction or elimination of complaints appears to be a clear indication of success, but that is not necessarily the case.

Occupants who see that their concerns are being heard may temporarily stop reporting discomfort or health symptoms, even if the actual cause of their complaints has not been addressed. Lingering complaints may also continue after successful mitigation if people have become upset over the handling of the problem. Ongoing (but reduced) complaints could also indicate that there were multiple IAQ problems and that one or more problems are still unresolved.

However, it can be very difficult to use measurements of contaminant levels as a means of determining whether air quality has improved. Concentrations of indoor air pollutants typically vary greatly over time; further, the specific contaminant measured may not be causing the problem.

If air samples are taken, readings taken before and after mitigation should be interpreted cautiously. It is important to keep the “before” and “after” conditions as identical as possible, except for the operation of the control strategy. For example, the same HVAC operation, building occupancy and climatic conditions should apply during both measurement periods. “Worst-case” conditions identified during the investigation should be used.

Measurements of airflows, ventilation rates, and air distribution patterns are the more reliable methods of assessing the results of control efforts. Airflow measurements taken during the building investigation can identify areas with poor ventilation; later they can be used to evaluate attempts to improve the ventilation rate, distribution, or direction of flow.

Studying air distribution patterns will show whether a mitigation strategy has successfully prevented a contaminant from being transported by airflow.

Persistent Problems

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

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

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

Wrapping it Up

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

The table below provides the maximum permissible level of contaminants for your ready reference.

	ASHRAE (2001)	NIOSH (2000)
Note: The ASHRAE recommendations are based on levels identified for increased occupant comfort. The NIOSH recommendations are occupational health standards. (Amounts are listed in Parts Per Million—ppm)		
Carbon Monoxide	9 ppm (8hrs) 35 ppm (1 hr)	35 ppm (8 hrs) 200 ppm (15 min)
Carbon Dioxide	1 000 ppm (8 hrs)	5 000 ppm 30 000 ppm (15 min)
Ozone	0.05 ppm 0.12 ppm (1 hr)	0.1 ppm (15 min)
Formaldehyde		0.016 ppm 0.1 ppm (15 min)
Sulphur Dioxide	0.03 ppm (1 y) 0.14 ppm (24 hrs)	2 ppm (8 hrs) 5 ppm (15 min)
Nitrogen Dioxide	0.055 ppm (1 yr)	
Particles	50 $\mu g/m^3$ (1 yr) 150 $\mu g/m^3$ (24 hrs)	