PDHonline Course M413 (4 PDH)

Indoor Air Quality – Part II: Mitigating Indoor Air Quality Problems

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This course is based on an EPA document, Building Air Quality: A Guide for Building Owners and Facility Managers, which was developed as a joint undertaking of the Indoor Air Division in the Office of Atmospheric and Indoor Air Programs of the United States Environmental Protection Agency and the National Institute for Occupational Safety and Health.

Introduction

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

Unfortunately, many commercial buildings do not meet the above mentioned standard for air quality even though good air quality is an important component of a healthy indoor environment. For the purposes of this document, the definition of good indoor air quality includes:

- Introduction and distribution of adequate ventilation air,
- Control of airborne contaminants, and
- Maintenance of acceptable temperature and relative humidity.

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

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

Good indoor air quality enhances occupant health, comfort, and workplace productivity.

Failure to respond promptly and effectively to building environmental problems can have consequences such as:

- Increasing health problems such as cough, eye irritation, headache, and allergic reactions, and, in some rare cases, resulting in life-threatening conditions (e.g., Legionnaire's disease, carbon monoxide poisoning)
- Reducing productivity due to discomfort or increased absenteeism

- Accelerating deterioration of furnishings and equipment
- Straining relations between landlords and tenants, employers and employees
- Creating negative publicity that could put rental properties at a competitive disadvantage
- Opening potential liability problems

The course is the second course in a series of two courses on indoor air quality. In the first course we looked at factors affecting indoor air quality and how to measure and evaluate indoor air quality. An explanation of how HVAC systems work was covered as well as issues with mold, mildew, asbestos and radon.

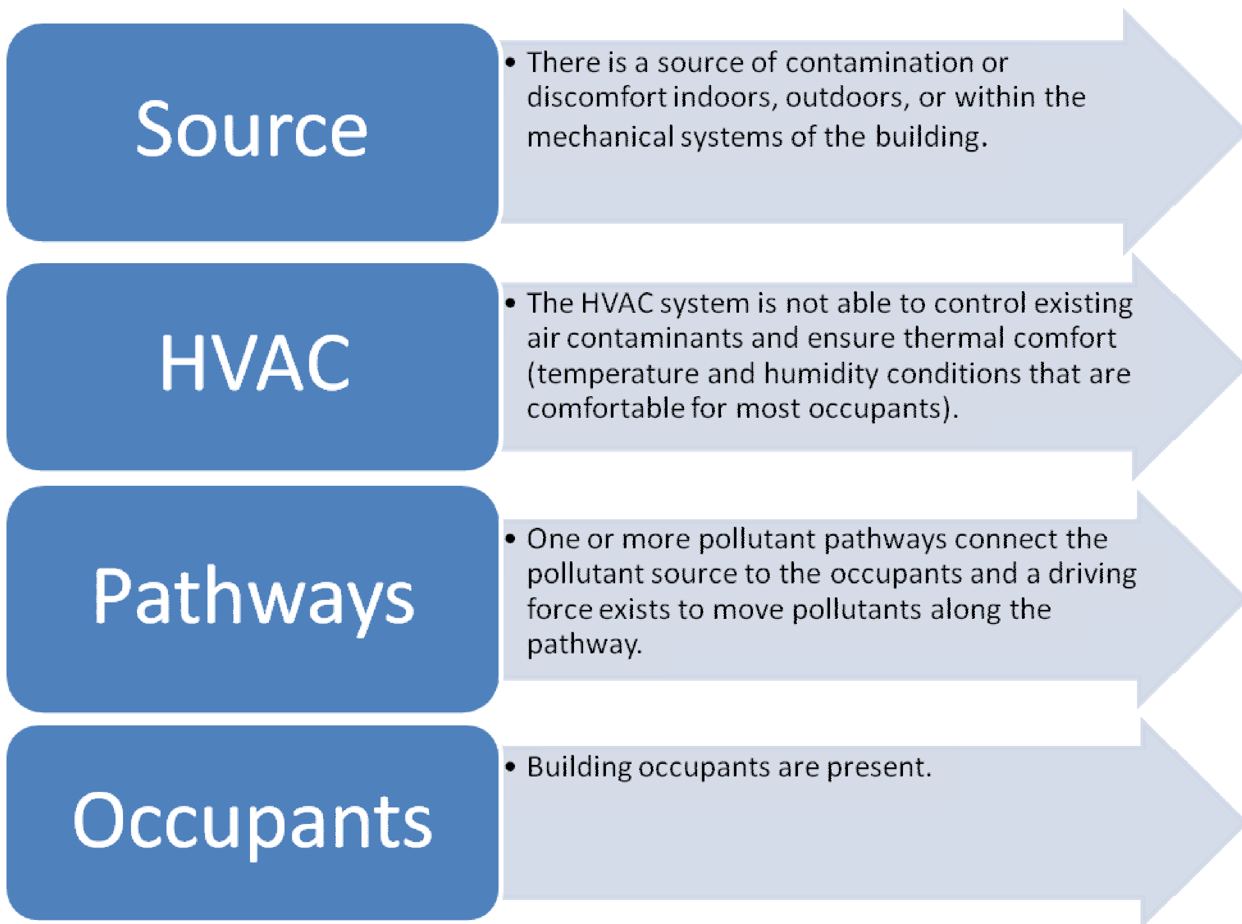
In this course, we discuss methods to mitigate indoor air quality problems and cover several common indoor air quality problems and potential solutions. But first, let's review some of the factors that impact a building's air quality that were covered in Part I of this series.

Chapter 1
Factors Affecting Indoor Air Quality

[Note: This is a brief overview of the factors affecting indoor air quality. Chapter One of Part I of this series covers this subject in much greater detail.]

The indoor environment in any building is a result of the interaction between the site, climate, building system, 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:



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, indoor air quality 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 five categories that follow. The examples given for each category are not intended to be a complete list.

HVAC systems like this can contribute to indoor air quality problems if they are not maintained

1. **Sources Outside Building**
   - Contaminated outdoor air
   - Emissions from nearby sources
   - Soil gas
   - Moisture or standing water promoting excess microbial growth

2. **Equipment**
   - HVAC system
   - Non-HVAC equipment

3. **Human Activities**
   - Personal activities
   - Housekeeping activities
   - Maintenance activities

4. **Building Components and Furnishings**
   - Locations that produce or collect dust or fibers
   - Unsanitary conditions and water damage
   - Chemicals released from building components or furnishings

5. **Other Sources**
   - Accidental events
   - Special use areas and mixed use buildings
   - Redecorating/remodeling/repair activities

HVAC System Design and Operation

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

A properly designed and functioning HVAC system:

1. Provides thermal comfort,
2. Distributes adequate amounts of outdoor air to meet ventilation needs of all building occupants, and
3. Isolates and removes odors and contaminants through pressure control, filtration, and exhaust fans.

Pollutant Pathways

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

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

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


HVAC duct work is another pathway for contamination

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

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.

Building Occupants

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

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

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

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

Chapter 2
Mitigating Indoor Air Quality Problems

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

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

- Facility operation and maintenance
- Housekeeping
- Shipping and receiving
- Purchasing
- Policymaking
- Staff training

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

Background: Controlling Indoor Air Problems

Chapter One 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:

Successful mitigation often involves a combination of these strategies. Each of these are discussed in detail below. Possible remedies for the other environmental stressors are discussed briefly in the following text.

Source Control

All efforts to prevent or correct indoor air quality problems should include an effort to identify and control pollutant sources. Source control is generally the most cost effective approach to mitigating indoor air quality 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
   - Prohibit smoking indoors or limit smoking to areas from which air is exhausted, not re-circulated
   - Relocate contaminant-producing equipment to an unoccupied, better ventilated, or exhaust-only ventilated space
   - Select products which produce fewer or less potent contaminants while maintaining adequate safety and efficacy
   - Modify other occupant activities

2. Seal or cover the source
    - Improve storage of materials that produce contaminants
    - Seal surfaces of building materials that emit VOCs such as formaldehyde

3. Modify the environment
    - After cleaning and disinfecting an area that is contaminated by fungal or bacterial growth, control humidity to make conditions inhospitable for re-growth

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. Re-growth of Micro-biological contaminants could occur unless humidity control or other steps, such as adding insulation to prevent surface condensation, are taken to make the environment inhospitable to micro-biological contaminants.

Ventilation

Ventilation modification is often used to correct or prevent indoor air quality problems. 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
    - Increase the total quantity of supply air (including outdoor air)
    - Increase the proportion of outdoor air to total air
    - Improve air distribution

2. Isolating or removing contaminants by controlling air pressure relationships
    - Install effective local exhaust at the location of the source
    - Avoid recirculation of air that contains contaminants

- Locate occupants near supply diffusers and sources near exhaust registers
- Use air-tightening techniques to maintain pressure differentials and eliminate pollutant pathways
- Make sure that doors are closed where necessary to separate zones

Diluting contaminants by increasing the flow of outdoor air can be accomplished by increasing the total supply airflow in the complaint area (e.g., opening supply diffusers, adjusting dampers) or at the air handling unit, (e.g., cleaning the filter on the supply fan). An alternative is to increase the proportion of outdoor air by adjusting the outdoor air intake damper, or installing minimum stops on variable air volume (VAV) boxes so that they meet the current outdoor air requirements of the ASHRAE standard. Table 1 shows the recommended ventilation requirements for several typical applications.

Table 1
Ventilation Recommendations for Selected Applications

Application	Area	Occupancy (People/1,000 ft^2)	CFM/Person	CFM/Ft^2
Food Service	Dining	70	20	
	Cafeteria	100	20	
	Lounges	100	30	
	Kitchen areas	20	15	
Offices	Office space	7	20	
	Reception	60	15	
	Conference rooms	50	20	
Public Spaces	Smoking area	70	60	
	Elevators	-	-	1.00
Retail	Basement & Street	30	-	0.30
	Upper floors	20	-	0.20
	Malls	20	-	0.20
	Smoking area	70	60	
Sports Venues	Spectator areas	150	15	
	Game rooms	70	25	
	Playing floors	30	20	
	Ballrooms	100	25	
Theaters	Lobbies	150	20	
	Auditorium	150	15	
Education	Classroom	50	15	
	Music room	50	15	
	Libraries	20	15	
	Auditoriums	150	15	
Hotels	Rooms	-	-	30/room

	Living rooms Lobbies Conference rooms Assembly rooms	- 30 50 120	- 15 20 15	30/room

Studies have shown that increasing ventilation rates to meet ASHRAE standards 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 indoor air quality problems. Diffusers should be properly selected, located, installed, and maintained so that supply air is evenly distributed and blends thoroughly with room air in the breathing zone.

Short circuiting occurs when clean supply air is drawn into the return air plenum before it has mixed with the dirtier room air and therefore fails to dilute contaminants. Mixing problems can be aggravated by temperature stratification. Stratification can occur, for example, in a space with high ceilings in which ceiling-mounted supply diffusers distribute heated air.

Note the side effects of increased ventilation:

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

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

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

Replacement air must be able to flow freely into the area from which the exhaust air is being drawn. It may be necessary to add door or wall louvers in order to provide a path for the make-up air.

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

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

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

Air Cleaning

The third indoor air quality 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. 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 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 indoor air quality 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. It is important to select an appropriate filter for the specific application and to make sure that the HVAC system will continue to perform as designed. Filters are rated by different standards (e.g., arrestance and dust spot) which measure different aspects of performance.

Electrostatic precipitation is another type of particulate control. It uses the attraction of charged particles to oppositely charged surfaces to collect airborne 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, OSHA has established standards for ozone in indoor air. The amount of ozone emitted from electrostatic precipitators varies from model to model.

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

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

Exposure Control

control is an administrative approach to mitigation that uses behavioral methods, such as: Scheduling contaminant-producing activities to avoid complaints and relocating susceptible individuals. Schedule contaminant-producing activities to occur during unoccupied periods and notify susceptible individuals about upcoming events 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 which unavoidably produce odors or dust. Move susceptible individuals away from the area where they experience symptoms controlling exposure by relocating susceptible individuals may be the only practical approach in a limited number of cases, but it is probably the least desirable option and should be used only when all other strategies are ineffective in resolving complaints.

Remedies for Complaints Not Attributed to Poor Air Quality

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

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

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

Chapter 3
Sample Problems and Solutions

In Chapter Two we reviewed a variety of problems that are often found in buildings. This section presents fifteen categories of indoor air quality problems. Specific problem examples are given, followed by solutions that have been used for that category of problem. The following is a summary of the fifteen sample problems.

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

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

Some solutions mentioned here 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.

Problem #1

Outdoor Air Ventilation Rate is Too Low

Examples include: Routine odors from occupants and normal office activities that result in problems such as drowsiness, headaches, discomfort; measured outdoor air ventilation rates that do not meet guidelines for outdoor air supply; peak CO_2 concentrations above 1,000 ppm which indicates inadequate ventilation; and corrosion of fan casing causes air bypassing and reduces airflow in system.

Solutions

1. Open, adjust or repair air distribution system
   - Outdoor air intakes
   - Mixing and relief dampers
   - Supply diffusers
   - Fan casings

2. Increase outdoor air within the design capacity of
   - Air handler
   - Heating and air conditioning equipment
   - Distribution system

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

Problem #2

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

An example includes a situation where the measured outdoor air meets guidelines at building air inlet, but there are zones where heat, routine odors from occupants, and normal office activities result in complaints such as drowsiness, headaches, and comfort complaints.

Solutions

Blocked return air grilles can create poor air distribution

1. Open, adjust, or repair air distribution system
   - Supply diffusers
   - Return registers

2. Ensure proper air distribution
   - Balance the air handling system
   - Make sure that there is an air gap at tops and bottoms of partitions to prevent dead air space
   - Relocate supply and/or return diffusers to improve air distribution

3. Seal leaky ductwork

4. Remove obstructions from return air plenum

5. Control pressure relationships
   - Install local exhaust in problem areas and adjust HVAC system to provide adequate make-up air
   - Move occupants so that they are closer to supply diffusers
   - Relocate identified contaminant sources closer to exhaust intakes

6. Limit activities that produce heat, odors, or contaminants

7. Design and install an appropriate ventilation system

Problem #3

Contaminant Entering Building From Outdoors

Examples of contaminants entering the building from outdoors include soil gases (radon, gasoline from tanks, methane from landfills), contaminants from nearby activities (roofing, dumpster, construction), an outdoor air intake near a contaminant source (parking, loading dock, building exhaust), and outdoor air containing pollutants or excess moisture (cooling tower mist entrained in outdoor air intake.)

Solutions

Air Dampers like this one can pull in outside contaminants

1. Remove the source, if it can be moved easily
   - Remove debris around outdoor air intake
   - Relocate dumpster

2. Reduce source (for example, shift time of activity to avoid occupied periods)
   - Painting, roofing, demolition
   - Housekeeping, pest control

3. Relocate elements of the ventilation system that contribute to entry of outdoor air contaminants
   - Separate outdoor air intakes from sources of odors, contaminants
   - Separate exhaust fan outlets from operable windows, doors, air intakes
   - Make rooftop exhaust outlets taller than intakes

4. Change air pressure relationships to control pollutant pathways
   - Install sub-slab depressurization to prevent entry of soil gas contaminants (radon, gases from landfills and underground tanks)
   - Pressurize the building interior relative to outdoors
   - Close pollutant pathways (e.g., seal cracks and holes)

5. Add special equipment to HVAC system

- Filtration equipment to remove pollutants

Problem #4

Occupant Activities Contribute to Air Contaminants or to Comfort Problems

Examples of occupant activities that contribute to problems include, smoking, special production activities such as print shops, laboratories, kitchens, and interference with HVAC system operation. Interference with HVAC system operation may include: Blockage of supply diffusers to eliminate drafts, turning off exhaust fans to eliminate noise, and use of space heaters, desktop humidifiers to remedy local discomfort

Solutions

Personal humidifiers like this one can contribute to air contaminants

1. Remove the source by eliminating the activity
   - Smoking
   - Use of desktop humidifiers and other personal HVAC equipment
   - Unsupervised manipulation of HVAC system

2. Reduce the source
   - 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
   - Smoking lounge, storage areas which contain contaminant sources
   - Laboratory hoods, kitchen range hoods (venting to outdoors, not re-circulating)

Problem #5

HVAC System is a Source of Biological Contaminants

The HVAC system can act as a source of contaminants by providing a hospitable environment for the growth of microorganisms and by then distributing biologically contaminated air within the building. This includes surface contamination by molds (fungi), bacteria in drain pans, interior of ductwork, and air filters and filters media (collected debris).

Solutions

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

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

Problem #6

HVAC System Distributes Contaminants

HVAC systems can create problems when unfiltered air bypasses filters. This can be caused by filter tracks that are loose, poorly-maintained filters that sag when they become overloaded with dirt and filters that are the wrong size. Another potential problem is recirculation of air that contains dust or other contaminants. This can be caused when the system re-circulates air from rooms containing pollutant sources, return air plenum draws air from rooms that should be exhausted (e.g. janitor's closets), and 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
    - Provide local exhaust at point sources of contaminants, adjust HVAC system to provide adequate make-up air, and test to verify performance
    - Increase proportion of outdoor air
    - Seal unplanned openings into return air plenums and provide alternative local ventilation

Poorly maintained air filtration equipment should be considered as a potential contaminate source

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

In addition to HVAC, other non-HVAC equipment can be a source or distribution mechanism for contaminants. Non-HVAC equipment such as wet process copiers, large dry process copiers, and engineering drawing reproduction machines can produce contaminants. It can also distribute contaminants, such as from elevators, which can act as pistons and draw contaminants from one floor to another.

Solutions

1. Install local exhaust near machines

2. Reschedule use to occur during periods of low occupancy

3. Remove source
    - Relocate occupants out of rooms that contain contaminant-generating equipment

- Relocate equipment into special use areas equipped with effective exhaust ventilation

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

Problem #8

Surface Contamination Due to Poor Sanitation or Accidents

Problems can be created from surface contamination due to poor sanitation or accidents. Biological contaminants can result in allergies or other diseases such as fungal, viral, bacterial and bird, insect, or rodent parts or droppings, hair, dander. Accidents may include spills of water, beverages, cleansers, paints, varnishes, mastics or specialized products (printing, chemical art supplies) and fire damage: soot, odors, and chemicals.

Solutions

1. Clean
    - HVAC system components
    - Materials and furnishings

2. Remove sources of microbiological contamination
    - Water-damaged carpet, furnishings, or building materials

3. Modify environment to prevent recurrence of microbiological growth
    - Improve HVAC system maintenance
    - Control humidity or surface temperatures to prevent condensation

4. Provide access to all items that require periodic maintenance Use local exhaust where corrosive materials are stored

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

Problem #9

Mold and Mildew Growth Due to Moisture from Condensation

Mold and mildew growth due to moisture from condensation may cause problems in areas such as Interior surfaces of walls near thermal bridges and carpeting on cold floors 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
    - Insulate thermal bridges
    - Improve air distribution

3. Reduce moisture levels in locations that are subject to condensation
    - Repair leaks
    - Increase ventilation (in cases where outdoor air is cold and dry)
    - Dehumidify (in cases where outdoor air is warm and humid)

4. Dry carpet or other textiles promptly after steam cleaning

5. Discard contaminated materials

Problem #10

Building Materials and Furnishings Produce Contaminants

Building materials and furnishings can produce contaminants such as odors from newly installed carpets, furniture, wall coverings newly dry-cleaned drapes or other textiles.

Solutions

1. Remove source with appropriate cleaning methods
   - Steam clean carpeting and upholstery, then dry quickly, ventilating to accelerate the drying process
   - Accept only fully dried, odorless dry cleaned products

2. Encapsulate source
   - Seal surfaces of building materials that emit formaldehyde

3. Reduce source
   - Schedule installation of carpet, furniture, and wall coverings to occur during periods when the building is unoccupied
   - Have supplier store new furnishings in a clean, dry, well-ventilated area until VOC out-gassing has diminished

4. Increase outdoor air ventilation
   - Total air supplied
   - Proportion of fresh air

5. Remove the materials that are producing the emissions and replace with lower emission alternatives

Problem #11

Housekeeping or Maintenance Activities Contribute to Problems

Cleaning products can emit chemicals, odors, and particulates that become airborne during cleaning (e.g., sweeping, vacuuming.) Contaminants can be released from painting, caulking, lubricating and problems are created when the frequency of maintenance is insufficient to eliminate contaminants.

Solutions

Housekeeping supplies also contribute to air quality problems

1. Remove source by modifying standard procedures or frequency of maintenance
    - Improve storage practices n shift time of painting, cleaning, pest control, other contaminant-producing activities to avoid occupied periods
    - Make maintenance easier by improving access to filters, coils, and other components

2. Reduce source
    - Select materials to minimize emissions of contaminants while maintaining adequate safety and efficacy
    - Use portable High Efficiency Particulate Arrestance (HEPA) vacuums vs. low efficiency paper-bag collectors

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

Problem #12

Specialized Use Areas as Sources of Contaminants

There are some specialized use areas that can be sources of contaminants. These areas may include food preparation, art or print rooms, and laboratories.

Solutions

1. Change pollutant pathway relationships
    - Run specialized use area under negative pressure relative to surrounding areas
    - Install local exhaust, adjust HVAC system to provide make-up air, and test to verify performance

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

Problem #13

Remodeling or Repair Activities Produce Problems

Temporary activities installation of new particleboard, partitions, carpet, or furnishings, painting, re-roofing, and demolition can produce odors and contaminants. Also, existing HVAC system may not provide adequate ventilation for new occupancy or arrangement of space.

Solutions

1. Modify ventilation to prevent recirculation of contaminants
    - Install temporary local exhaust in work area, adjust HVAC system to provide make-up air, and test to verify performance

- Seal off returns in work area
- Close outdoor air damper during re-roofing

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

3. Reduce source by careful materials selection and installation
    - Select materials to minimize emissions of contaminants while maintaining adequate safety and efficacy
    - Have supplier store new furnishings in a clean, dry, well-ventilated area until VOC out-gassing has diminished
    - Request installation procedures that limit emissions of contaminants

4. Modify HVAC or wall partition layout if necessary
    - Partitions should not interrupt airflow
    - Relocate supply and return diffusers
    - Adjust supply and return air quantities
    - Adjust total air and/or outdoor air supply to serve new occupancy

Problem #14

Combustion Gases

Combustion odors can indicate the existence of a serious problem. One combustion product, carbon monoxide, is an odorless gas. Carbon monoxide poisoning can be life-threatening. Vehicle exhaust is a source of combustion gases and offices above an underground parking garage and rooms near a loading dock or service garage may be may have combustion gas issues. Combustion gas can come from equipment because of spillage from inadequately vented appliances, cracked heat exchanger, and re-entrainment because local chimney is too low.

Solutions

1. Seal to remove pollutant pathway
    - Close openings between the contaminant source and the occupied space
    - Install well-sealed doors with automatic closers between the contaminant source and the occupied space

5. Remove source
   - Improve maintenance of combustion equipment
   - Modify venting or HVAC system to prevent back drafting
   - Relocate holding area for vehicles at loading dock, parking area
   - Turn off engines of vehicles that are waiting to be unloaded

6. Modify ventilation system
   - Install local exhaust in underground parking garage
   - Relocate fresh air intake (move away from source of contaminants

7. Modify pressure relationships
   - Pressurize spaces around area containing source of combustion gases

Problem #15

Serious Building-Related Illness

Some building-related illnesses can be life threatening. Even a single confirmed diagnosis should provoke an immediate and vigorous response. Examples include; Legionnaire's disease and hypersensitivity pneumonitis.

Solutions

1. Work with public health authorities
   - Evacuation may be recommended or required

2. Remove source
   - Drain, clean, and decontaminate drip pans, cooling towers, room unit air conditioners, humidifiers, dehumidifiers, and other habitats of Legionella, fungi, and other organisms using appropriate protective equipment
   - Install drip pans that drain properly
   - Provide access to all the items that must be cleaned, drained, or replaced periodically
   - Modify schedule and procedures for improved maintenance

3. Discontinue processes that deposit potentially contaminated moisture in air distribution system
    - Air washing
    - Humidification
    - Cease nighttime shutdown of air handlers

Chapter 4
Evaluation of Indoor Air Quality Plans

Mitigation efforts should be evaluated by considering the following criteria:

- Permanence
- Operating principle
- Degree to which the strategy fits the job
- Ability to institutionalize the solution
- Durability
- Installation and operating costs
- Conformity with codes

Permanence

Mitigation efforts that create permanent solutions to indoor air problems are clearly superior to those that provide temporary solutions. Opening windows or running air handlers on full outdoor air may be suitable mitigation strategies for a temporary problem such as out-gassing 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 re-growth.

Operating Principle

The most economical and successful solutions to indoor air quality 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 indoor air quality problem is caused by the introduction of outdoor air that contains contaminants, increased general ventilation will only make the situation worse.

Degree to Which the Strategy Fits the Job

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

If mechanical equipment is needed to correct the indoor air quality 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 re-circulated.

Ability to Institutionalize the Solution

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

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

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

Installation and Operating Costs

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

Conformity with Codes

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

Some problems involve severe contamination and these situations may require extraordinary measures to resolve. Table 2, is an outline of one approach to dealing with severe contamination.

Table 2

Managing Mitigation Projects Involving Severe Contamination

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

Judging the Success of a Mitigation Effort

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

- Reduced complaints
- Measurement of properties of the indoor air

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 complaints could also indicate that there were multiple indoor air quality 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.

Summary

A healthy indoor environment is one in which the surroundings contribute to productivity, comfort, and a sense of health and well being. The indoor air is free from significant levels of odors, dust and contaminants and circulates to prevent stuffiness without creating drafts.

Failure to respond promptly and effectively to building environmental problems can have consequences such as:

- Increasing health problems such as cough, eye irritation, headache, and allergic reactions, and, in some rare cases, resulting in life-threatening conditions (e.g., Legionnaire's disease, carbon monoxide poisoning)
- Reducing productivity due to discomfort or increased absenteeism
- Accelerating deterioration of furnishings and equipment
- Straining relations between landlords and tenants, employers and employees
- Creating negative publicity that could put rental properties at a competitive disadvantage
- Opening potential liability problems

Mitigating air quality problems involves controlling the sources of contaminants, ventilation, filtering, and minimizing exposure to harmful contaminants. This course has covered several examples of how to mitigate these issues and how to evaluate the results of the mitigation strategies.

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