Factors Affecting Indoor Air Quality

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

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

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

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

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

Occupants: building occupants are present.

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

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

SOURCES OF INDOOR AIR CONTAMINANTS

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

Sources Outside Building

Contaminated outdoor air

- pollen, dust, fungal spores
- industrial pollutants
- general vehicle exhaust

Emissions from nearby sources

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

Soil gas

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

Moisture or standing water promoting excess microbial growth

- rooftops after rainfall
- crawlspace

Equipment

HVAC system

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

Non-HVAC equipment

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

Human Activities

Personal activities

- smoking
- cooking
- body odor
- cosmetic odors

Housekeeping activities

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

Maintenance activities

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

Building Components and Furnishings

Locations that produce or collect dust or fibers

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

Unsanitary conditions and water damage

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

Chemicals released from building components or furnishings

- volatile organic compounds or
- inorganic compounds

Other Sources

Accidental events

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

Special use areas and mixed use buildings

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

Redecorating/remodeling/repair activities

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

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

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HVAC SYSTEM DESIGN AND OPERATION

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

A properly designed and functioning HVAC system:

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

Thermal Comfort

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

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

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

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

Ventilation to Meet Occupant Needs

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

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

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

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

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

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

Control of Odors and Contaminants

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

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

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

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

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

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

POLLUTANT PATHWAYS AND DRIVING FORCES

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

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

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

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

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

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

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

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

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

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

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

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

BUILDING OCCUPANTS

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

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

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

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

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

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

Types of Symptoms and Complaints

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

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

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

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

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

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

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

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

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

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