IAQ Building Education and Assessment Model (I-BEAM)

Overview

I-BEAM Text Modules and Visual Reference Modules

The Indoor Air Quality Building Education and Assessment Model (I-BEAM) is a guidance tool designed for use by building professionals and others interested in indoor air quality in commercial buildings. I-BEAM updates and expands EPA's Building Air Quality guidance and was designed to be a comprehensive state-of-the-art guidance for managing IAQ in commercial buildings. I-BEAM contains text, animation/visual, and interactive/calculation components that can be used to perform several tasks including:

- conducting an indoor air quality (IAQ) building audit;
- diagnosing and resolving IAQ related health problems;
- establishing an IAQ management and maintenance program to reduce IAQ risks;
- planning IAQ compatible energy projects;
- protecting occupants from exposures to construction/renovation contaminants; and
- calculating the cost, revenue, and productivity impacts of planned IAQ activities.

Contents

- Overview of I-BEAM
- Overview of Text Modules
- Overview of Visual Reference Modules
- IAQ Budgets and Accounts
- I-BEAM Forms

- Glossary of Terms
- Related Links
- Bibliography

Note: This guidance was designed to be a web-only resource. However, PDF versions of each of the text modules are being made available. Please note that these PDF files represent the version of I-BEAM on the date the files were created. A version of this Overview is available now. Check back in a couple of weeks for the remaining files.

Overview (PDF, 3 pp, 37KB, About PDF)

Indoor Air Quality (IAQ)

This material integrates information from a variety of sources, with a style that is crisp, to the point, and action oriented.

- I-BEAM Text Modules
- IAQ Budgets and Accounts
- Visual Reference Modules

I-BEAM also includes **Forms**, **Glossary of IAQ Terms**, and **Related sites**, as well as other resources.

I-BEAM Text Modules

- **Overview**

- **Fundamentals of IAQ in Buildings**: What are the fundamentals to understanding indoor air quality? In this section, we provide a rudimentary framework for understanding how indoor and outdoor sources of pollution, heat and humidity, together with the ventilation and air conditioning systems affect the indoor air quality in buildings. We also begin to address methods of controlling those factors in order that the quality of the air which occupants experience provides for their health, comfort and performance.

- **Heating, Ventilation, and Air-conditioning (HVAC)**: What are the elements of the heating, ventilating, and air conditioning (HVAC) system that are important to IAQ? What information is important to developing protocols for the operating set points and schedules consistent with good IAQ performance?

- **IAQ Maintenance and Housekeeping Programs**: Good preventive maintenance and housekeeping practices are at the core of establishing and maintaining good indoor air quality in buildings. In this module, we describe the essential elements of preventive maintenance and housekeeping programs and describe their relationship to IAQ. The interactive modules relating to PM or Housekeeping contain detailed maintenance and housekeeping schedules which the user can modify to satisfy individual building requirements, or to establish an IAQ maintenance and housekeeping budget.

- **Indoor Air Quality and Energy Efficiency**: This section examines the relationship between IAQ and energy efficiency. Because many attempts to save energy in the 1970s and 1980s resulted in sick building syndrome and gave rise to minimum ventilation standards to protect IAQ, there has been a growing but erroneous conception that IAQ and energy efficiency are incompatible goals. Recent studies demonstrate that the two goals are compatible and that the true trade-off is either minimal or manageable.

- **Diagnosing and Solving Problems**: How does the knowledge obtained by working with I-BEAM help dedicated building personnel to develop sufficient expertise to solve most IAQ complaints? In this section, we describe two approaches to the indoor air quality diagnostic process for buildings - one for industrial facilities and one for commercial facilities.

- **Renovation and New Construction**: What actions are important to protect and improve IAQ during each phase of the design and construction process?

- **Managing for Indoor Air Quality**: How can I establish a management program that contains all the appropriate elements needed to manage a building for good IAQ?

IAQ Budgets and Accounts

Catalogue all of your IAQ activities and IAQ expenses, and assess the impact of those activities on your bottom line. Further, you can use this module to document your IAQ actions and expenses, and to develop a marketing plan. By marketing IAQ, you take advantage of the evidence that IAQ affects employee moral and performance, and the evidence that an IAQ program can be an attractive feature for existing and prospective tenants.

Visual Reference Module Index

The Visual Reference module contains pictures and animations of IAQ problems and solutions. Learn about the IAQ issues contained in each picture. You may find explanations in text, or in other visual guides which show air movement flows, or pollutant flows as various elements in the building are changed.

Please note: The animated series modules use animated GIF files which are about 2MB in file size. If you have dial-up access to the internet, it may be a moment before the graphics load.

Picture Series

1. Controlling Common Outdoor Sources
2. Controlling Common Indoor Sources
3. Controlling Pollution Pathways
4. Control Moisture and Mold
5. Special Issues In Construction and Renovation
6. Preventive Maintenance Sustains Good IAQ
7. Be Responsive to Occupant Needs

Animation Series

1. Controlling Ventilation Air Flows
2. Pressure Relationships
3. Containing Construction Contaminants
4. Pollution Flows in Underground Garage

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: Fundamentals of IAQ in Buildings

This module provides the fundamentals to understanding indoor air quality. It provides a rudimentary framework for understanding how indoor and outdoor sources of pollution, heat and humidity, together with the ventilation and air conditioning systems affect the indoor air quality in buildings. It also begins to address methods of controlling those factors in order that the quality of the air which occupants experience provides for their health, comfort and performance.

- **Overview of Indoor Air Quality in I-BEAM**
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  - Why is IAQ Important to Building Managers?
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  - Building Associated Illnesses
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- **Building Factors Affecting Indoor Air Quality**
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  - Types of Pollutants and Potential Sources
- **Contaminant Sources**

I-BEAM Text Modules

- **Fundamentals of IAQ in Buildings**
- Heating, Ventilation, and Air-conditioning (HVAC)
- IAQ Maintenance and Housekeeping Programs
- Indoor Air Quality and Energy Efficiency
- Diagnosing and Solving Problems
- Renovation and New Construction
- Managing for Indoor Air Quality
- IAQ Budgets and Accounts

- Overview of I-BEAM
- Overview of Text Modules
- Overview of Visual Reference Modules
- IAQ Budgets and Accounts
- I-BEAM Forms

Fundamentals of IAQ in Buildings
(PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

  - Indoor Sources
  - Outdoor Sources

- **Protocols for Managing Major Sources of Pollution in Buildings**

- **Pollution Transport**

  - Air Movement and Pressure
  - Driving Forces
  - Common Unplanned Pathways

- **Ventilation**

  - Exhaust Ventilation
  - Dilution Ventilation
  - Ventilation Measurements

Overview of Indoor Air Quality in I-BEAM

What is Indoor Air Quality?

Indoor air quality (IAQ) in I-BEAM refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions that affect the health, comfort, and performance of occupants. Other factors affecting occupants, such as light and noise, are important indoor environmental quality considerations, but are not treated in I-BEAM as core elements of indoor air quality.

Why is IAQ Important to Building Managers?

Buildings exist to protect people from the elements and to otherwise support human activity. Buildings should not make people sick, cause them discomfort, or otherwise inhibit their ability to perform. How effectively a building functions to support its occupants and how efficiently the building operates to keep costs manageable is a measure of the building's performance.

The growing proliferation of chemical pollutants in consumer and commercial products, the tendency toward tighter building envelopes and reduced ventilation to save energy, and pressures to defer maintenance and other building services to reduce costs have fostered indoor air quality problems in many buildings. Occupant complaints of odors, stale and stuffy air, and symptoms of illness or discomfort breed undesirable conflicts between occupants or tenants and building managers. Lawsuits sometimes follow.

If indoor air quality is not well managed on a daily basis, remediation of ensuing problems and/or resolution in court can be extremely costly. So it helps to understand the causes and consequences of indoor air quality and to manage your building to avoid these problems.

How Can I-BEAM Help?

How to design, construct, and manage buildings economically and still satisfy indoor air quality needs of building occupants is a question which looms large for many building managers. It is THE fundamental question addressed by I-BEAM. I-BEAM helps you manage your building to prevent indoor air quality problems and to solve them when they occur. The tools provided also help you to document your IAQ activities so you can market your IAQ program and support a legal defense. Finally you can use I-BEAM to evaluate the impact of IAQ activities on your bottom line.

Occupant Symptoms Associated with Poor Indoor Air Quality

Human responses to pollutants, climatic factors, and other stressors such as noise and light are generally categorized according to the type and degree of responses and the time frame in which they occur. Building managers should be generally familiar with these categories, leaving detailed knowledge to health and safety professionals.

Acute Effects

Acute effects are those that occur immediately (e.g., within 24 hours) after exposure. Chemicals released from building materials may cause headaches, or mold spores may result in itchy eyes and runny noses in sensitive individuals shortly after exposure. Generally, these effects are not long lasting and disappear shortly after exposure ends. However, exposure to some biocontaminants (fungi, bacteria, viruses) resulting from moisture problems, poor maintenance, or inadequate ventilation have been known to cause serious, sometimes life threatening respiratory diseases which themselves can lead to chronic respiratory conditions.

Chronic Effects

Chronic effects are long-lasting responses to long term or frequently repeated exposures. Long term exposures to even low concentrations of some chemicals may induce chronic effects. Cancer is the most commonly associated long term health consequence of exposure to indoor air contaminants. For example, long term exposures to environmental tobacco smoke, radon, asbestos, and benzene increases cancer risk.

Discomfort

Discomfort is typically associated with climatic conditions but building contaminants may also be implicated. People complain of being too hot or too cold or experience eye, nose or throat irritation because of low humidity. However, reported symptoms can be difficult to interpret. Complaints that the air is "too dry" may result from irritation from particles on the mucous membranes rather than low humidity, or "stuffy air" may mean that the temperature is too warm or there is lack of air movement, or "stale air" may mean that there is a mild but difficult to identify odor. These conditions may be unpleasant and cause discomfort among occupants, but there is usually no serious health implication involved. Absenteeism, work performance and employee morale, however, can be seriously affected when building managers fail to resolve these complaints.

Performance Effects

Significant measurable changes in people's ability to concentrate or perform mental or physical tasks have been shown to result from modest changes in temperature and relative humidity. In addition, recent studies suggest that the similar effects are associated with indoor pollution due to lack of ventilation or the presence of pollution sources. Estimates of performance losses from poor indoor air quality for all buildings suggest a 2-4% loss on average. Future research should further document and quantify these effects.

Building Associated Illnesses

The rapid emergence of indoor air quality problems and associated occupant complaints have led to terms which describe illnesses or effects particularly associated buildings. These include sick building syndrome, building related illness, and multiple chemical sensitivity.

Sick Building Syndrome (SBS)

Sick Building Syndrome (SBS) is a catch-all term that refers to a series of acute complaints for which there is no obvious cause and where medical tests reveal no particular abnormalities. The symptoms display when individuals are in the building but disappear when they leave. Complaints may include such symptoms as irritation of the eyes, nose and throat; headache; stuffy nose; mental fatigue; lethargy, and skin irritation. These complaints are often accompanied by non-specific complaints such as the air is stuffy or stale. A single causative agent (e.g., contaminant) is seldom identified and complaints may be resolved when building operational problems and/or occupant activities identified by investigators are corrected. Experience in resolving SBS complaints has led to many of the suggestions for "good practice" found in I-BEAM.

Increased absenteeism, reduced work efficiency, and deteriorating employee morale are the likely outcomes of SBS problems which are not quickly resolved.

Building Related Illness (BRI)

Building related illness refers to an defined illness with a known causative agent resulting from exposure to the building air. While the causative agent can be chemical (e.g., formaldehyde), it is often biological. Typical sources of biological contaminants are humidification systems, cooling towers, drain pans or filters, other wet surfaces, or water damaged building material. Symptoms may be specific or mimic symptoms commonly associated with the flu, including fever, chills, and cough. Serious lung and respiratory conditions can occur. Legionnaires' disease, hypersensitivity pneumonitis, and humidifier fever are common examples of building related illness.

Multiple Chemical Sensitivity (MCS)

It is generally recognized that some persons can be sensitive to particular agents at levels which do not have an observable affect in the general population. In addition, it is recognized that certain chemicals can be sensitizers in that exposure to the chemical at high levels can result in sensitivity to that chemical at much lower levels.

Some evidence suggests that a subset of the population may be especially sensitive to low levels of a broad range of chemicals at levels common in today's home and working environments. This apparent condition has come to be known as multiple chemical sensitivity (MCS).

Persons reported to have MCS apparently have difficulty being in most buildings. There is significant professional disagreement concerning whether MCS actually exists and what the underlying mechanism might be. Building managers may encounter occupants who have been diagnosed with MCS. Resolution of complaints in such circumstances may or may not be possible with the guidance provided in I-BEAM. Responsibility to accommodate such individuals is subject to negotiation and may involve arrangements to work at home or in a different location.

Building Factors Affecting Indoor Air Quality

Factors Affecting Indoor Climate

The thermal environment (temperature, relative humidity and airflow) are important dimensions of indoor air quality for several reasons. First, many complaints of poor indoor air may be resolved by simply altering the temperature or relative humidity. Second, people that are thermally uncomfortable will have a lower tolerance to other building discomforts. Third, the rate at which chemicals are released from building materials is usually higher at higher building temperatures. Thus, if occupants are too warm, it is also likely that they are being exposed to higher pollutant levels.

Indoor thermal conditions are controlled by the heating, ventilating, and air conditioning (HVAC) system. How well the thermal environment is controlled depends on the design and operating parameters of the system, and on the heat gains and losses in the space being controlled. These gains and losses are principally determined by indoor sources of heat, the heat gains from sunlight, the heat exchange through the thermal envelope, and the outdoor conditions and outdoor air ventilation rate.

Factors Affecting Indoor Air Pollution

Much of the building fabric, its furnishings and equipment, its occupants and their activities produce pollution. In a well functioning building, some of these pollutants will be directly exhausted to the outdoors and some will be removed as outdoor air enters the building and replaces the air inside. The air outside may also contain contaminants which will be brought inside in this process. This air exchange is brought about by the mechanical introduction of outdoor air (outdoor air ventilation rate), the mechanical exhaust of indoor air, and the air exchanged through the building envelope (infiltration and exfiltration).

Pollutants inside can travel through the building as air flows from areas of higher atmospheric pressure to areas of lower atmospheric pressure. Some of these pathways are planned and deliberate so as to draw pollutants away from occupants, but problems arise when unintended flows draw contaminants into occupied areas. In addition, some contaminants may be removed from the air through natural processes, as with the adsorption of chemicals by surfaces or the settling of particles onto surfaces. Removal processes may also be deliberately incorporated into the building systems. Air filtration devices, for example, are commonly incorporated into building ventilation systems.

Thus, the factors most important to understanding indoor pollution are:

a. indoor sources of pollution,
b. outdoor sources of pollution,
c. ventilation parameters,
d. airflow patterns and pressure relationships, and
e. air filtration systems.

Types of Pollutants

Common pollutants or pollutant classes of concern in commercial buildings along with common sources of these pollutants are provided below.

Indoor Pollutants and Potential Sources

Pollutant or Pollutant Class	Potential Sources
Environmental Tobacco Smoke	Lighted cigarettes, cigars, pipes
Combustion Contaminants	Furnaces, generators, gas or kerosene space heaters, tobacco products, outdoor air, vehicles.
Biological Contaminants	Wet or damp materials, cooling towers, humidifiers, cooling coils or drain pans, damp duct insulation or filters, condensation, re-entrained sanitary exhausts, bird droppings, cockroaches or rodents, dustmites on upholstered furniture or carpeting, body odors.
Volatile Organic Compounds (VOCs)	Paints, stains, varnishes, solvents, pesticides, adhesives, wood preservatives, waxes, polishes, cleansers, lubricants, sealants, dyes, air fresheners, fuels, plastics, copy machines, printers, tobacco products, perfumes, dry cleaned clothing.
Formaldehyde	Particle board, plywood, cabinetry, furniture, fabrics.
Soil gases (radon, sewer gas, VOCs, methane)	Soil and rock (radon), sewer drain leak, dry drain traps, leaking underground storage tanks, land fill
Pesticides	Termiticides, insecticides, rodenticides, fungicides, disinfectants, herbicides.
Particles and Fibers	Printing, paper handling, smoking and other combustion, outdoor sources, deterioration of materials, construction/renovation, vacuuming, insulation.

Contaminant Sources

Indoor Sources

Identified below are some sources of contaminants commonly found in office buildings and offers some measures for maintaining control of these contaminants. Follow these measures to help maintain a healthy indoor environment.

Category/Common Sources

1. **Housekeeping and Maintenance (Includes)** - cleansers, waxes and polishes, disinfectants, air fresheners, adhesives, janitor's/storage closets, wet mops, drain cleaners, vacuuming, paints and coatings, solvents, pesticides, and lubricants

   Tips for Mitigation and Control

   - Use low-emitting products
   - Avoid aerosols and sprays
   - Dilute to proper strength (manufacturer's instructions)
   - Do not overuse; use during unoccupied hours
   - Use proper protocol when diluting and mixing
   - Store properly with containers closed and lid tight
   - Use exhaust ventilation for storage spaces (eliminate return air)
   - Clean mops: store mop top up to dry
   - Avoid “air fresheners”—clean and exhaust instead
   - Use high efficiency vacuum bags/filters
   - Use Integrated Pest Management

2. **Occupant-Related Sources (Includes) -** Tobacco products, Office equipment (e.g., Printers and copiers), cooking/microwave, art supplies, marking pens, paper products, personal products (e.g., perfume), and tracked in dirt/pollen

   Tips for Mitigation and Control

   - Smoking policy
   - Use exhaust ventilation with pressure control for major local sources
   - Low emitting art supplies/marking pens
   - Avoid paper clutter
   - Education material for occupants and staff

3. **Building Uses as Major Sources (Includes) -** print/photocopy shop, dry cleaning, science laboratory, medical office, hair/nail salon, cafeteria, and pet store

   Tips for Mitigation and Control

   - Use exhaust ventilation and pressure control
   - Use exhaust hoods where appropriate; check hood airflows

4. **Building-Related Sources (Includes)** - plywood/compressed wood, construction adhesives, asbestos products, insulation, wall/ floor coverings (vinyl/plastic), carpets/carpet adhesives, wet building products, transformers, upholstered furniture, and renovation/remodeling

   Tips for Mitigation and Control

   - Use low emitting products
   - Air out in an open/ventilated area before installing
   - Increase ventilation rates during and after installing
   - Keep material dry prior to enclosing
   - Use renovation guidelines

5. **HVAC system (Includes)** - contaminated filters, contaminated duct lining, dirty drain pans, humidifiers, lubricants, refrigerants, mechanical room, maintenance activities, and combustion appliances (e.g., boilers/furnaces, DHW, generators, and stoves)

   Tips for Mitigation and Control

- Perform HVAC preventive maintenance
- Use filter change protocol
- Clean drain pans; proper slope and drainage
- Use potable water for steam humidification
- Keep duct lining dry; move lining outside of duct if possible
- Fix leaks/clean spills (see filter change protocol)
- Maintain spotless mechanical room (not a storage area)
- Avoid back drafting
- Check/maintain flues from boiler to outside
- Keep combustion appliances properly tuned
- Disallow unvented combustion appliances
- Perform polluting activities during unoccupied hours

6. **Moisture (Includes)** - Mold

   Tips for Mitigation and Control

   - Keep building dry
   - Mold and Moisture Control Protocol

7. **Vehicles (Includes)** - Underground/attached garage

   Tips for Mitigation and Control

   - Use exhaust ventilation
   - Maintain garage under negative pressure relative to the building
   - Check air flow patterns frequently
   - Monitor CO

Outdoor Sources

Identified below are common sources of contaminants that are introduced from outside buildings. These contaminants frequently find their way inside through the building shell, openings, or other pathways to the inside.

1. **Ambient Outdoor Air (Includes)** - air quality in the general area

   Tips for Mitigation and Control

   - Filtration or air cleaning of intake air

2. **Vehicular Sources (Includes) -** local vehicular traffic, vehicle idling areas, and loading dock

   Tips for Mitigation and Control

   - Locate air intake away from source
   - Require engines shut off at loading dock
   - Pressurize building/zone
   - Add vestibules/sealed doors near source

3. **Commercial/Manufacturing Sources (Includes)** - laundry or dry cleaning, restaurant, photo-processing, automotive shop/gas station, paint shop, electronics manufacture/assembly, and various industrial operations

   Tips for Mitigation and Control

- Locate air intake away from source
- Pressurize building relative to outdoors
- Consider air cleaning options for outdoor air intake
- Use landscaping to block or redirect flow of contaminants, but not too close to air intakes

4. **Utilities / Public Works (Includes)** - utility power plant, incinerator, and water treatment plant

Tips for Mitigation and Control

- Locate air intake away from source
- Pressurize building relative to outdoors
- Consider air cleaning options for outdoor air intake
- Use landscaping to block or redirect flow of contaminants, but not too close to air intakes

5. **Agricultural** (Includes) - pesticide spraying, processing or packing plants, and ponds

Tips for Mitigation and Control

- Locate air intake away from source
- Pressurize building relative to outdoors
- Consider air cleaning options for outdoor air intake
- Use landscaping to block or redirect flow of contaminants, but not too close to air intakes

6. **Construction / Demolition**

Tips for Mitigation and Control

- Pressurize building
- Use walk-off mats

7. **Building Exhaust (Includes)** - bathrooms exhaust, restaurant exhaust, air handler relief vent, and exhaust from major tenant (e.g., dry cleaner)

Tips for Mitigation and Control

- Separate exhaust or relief from air intake
- Pressurize building

8. **Water Sources (Includes) -** pools of water on roof and cooling tower mist

Tips for Mitigation and Control

- Proper roof drainage
- Separate air intake from source of water
- Treat and maintain cooling tower water

9. **Birds and Rodents (Includes)** - fecal contaminants and bird nesting

Tips for Mitigation and Control

- Bird proof intake grills
- Consider vertical grills

- Use Integrated Pest Management

10. **Building Operations and Maintenance (Includes)** - trash and refuse area, chemical/fertilizers/grounds keeping storage, and painting/roofing/sanding

Tips for Mitigation and Control

- Separate source from air intake
- Keep source area clean/lids on tight
- Isolate storage area from occupied areas

11. **Ground Sources (Includes)** - soil gas, sewer gas, and underground fuel storage tanks

Tips for Mitigation and Control

- Depressurize soil
- Seal foundation and penetrations to foundation
- Keep air ducts away from ground sources

Protocols for Managing Major Sources of Pollution in Buildings

<table>
<tr><th>Type of Protocol</th><th>Solution</th></tr>
<tr><td>Remodeling and Renovation</td><td>Use effective strategies for material selection and installation.
Isolate construction activity from occupants.</td></tr>
<tr><td>Painting</td><td>Establish a protocol for painting and insure that the protocol is followed by both in-house personnel and by contractors.
Use low VOC emission, fast drying paints where feasible.
Paint during unoccupied hours.
Keep lids on paint containers when not in use.
Ventilate the building with significant quantities of outside air during and after painting. Insure a complete building flush prior to occupancy.
Use more than normal outside air ventilation for some period after occupancy.
Avoid spraying, when possible.</td></tr>
<tr><td>Pest Control Integrated Pest Management</td><td>Use or require the use of Integrated Pest Management by pest control contractors in order to minimize the use of pesticides when managing pests.
Control dirt, moisture, clutter, foodstuff, harborage, and building penetrations to minimize pests.
Use baits and traps rather than pesticide sprays where possible.
Avoid periodic pesticide application for “prevention” of pests.
Use pesticides only where pests are located.
Use pesticide specifically formulated for the targeted pest.
Apply pesticides only during unoccupied hours.
Ventilate the building with significant quantities of outside air during and after applications.</td></tr>
</table>

	• Insure a complete building flush prior to occupancy. • Use more than normal outside air ventilation for some period after occupancy. • Notify occupants prior to occupation. • If applying outside, keep away from air intake.

Shipping and Receiving	• Establish and enforce a program to prevent vehicle contaminants from entering the building.
	    • Do not allow idling of vehicles at the loading dock. Post signs and enforce the ban.
	    • Pressurize the receiving area relative to the outside to insure that contaminants from the loading area do not enter the building. Use pressurized vestibules and air locks if necessary.
	    • Periodically check the pressure relationships and compliance with the protocol.
	    • Notify delivery company supervisors of policy.

Establish and Enforce a Smoking Policy	Environmental tobacco smoke (ETS) is a major indoor air contaminant. A smoking policy may take one of two forms: • A smoke-free policy which does not allow smoking in any part of the building. • A policy that restricts smoking to designated smoking lounges only. (Partial policies such as allowing smoking only in private offices are not effective.)
Smoking Lounge Requirements	A designated smoking lounge must have the following features to be effective in containing ETS. • The lounge should be fully enclosed. • The lounge should be sealed off from the return air plenum. • The lounge should have exhaust ventilation directly to the outside at 60cfm per occupant (using maximum occupancy). • Transfer air from occupied spaces may be used as make up air. • The lounge should be maintained under negative pressure relative to the surrounding occupied spaces.
Managing Moisture and Mold (See also EPA's Mold Remediation Guidelines)	Mold thrives in the presence of water. The secret to controlling mold is to control moisture and relative humidity • Keep relative humidity below 60% (50%, if feasible, to control dust mites) Keep all parts of the building dry that are not designed to be wet • Adequately insulate exterior walls or ceilings to avoid condensation on cold surfaces • Insulate cold water pipes to avoid sweating • Clean spills immediately. Thoroughly clean and dry liquid spills on porous surfaces such as carpet within 24 hours, or discard the material • Do not allow standing water in any location • Maintain proper water drainage around the perimeter of the building • Provide sufficient exhaust in showers or kitchen areas producing steam

	Thoroughly clean areas that are designed to be wet • Wash floors and walls often where water accumulates (e.g., showers) • Clean drain pans often and insure a proper slope to keep water draining • Insure proper maintenance and treatment of cooling tower operations Discard all material with signs of mold growth • Discard furniture, carpet, or similar porous material having a persistent musty odor • Discard furniture, carpet, or similar porous material that has been wet for more than 24 hours • Discard ceiling tiles with visible water stains

Pollution Transport

Air Movement and Pressure

Contaminants reach occupant breathing-zones by traveling from the source to the occupant by various pathways. Normally, the contaminants travel with the flow of air.

Air moves from areas of high pressure to areas of low pressure. That is why controlling building air pressure is an integral part of controlling pollution and enhancing building IAQ performance.

Air movement should be from occupants, toward a source, and out of the building rather than from the source to the occupants and out the building. Pressure differences will control the direction of air motion and the extent of occupant exposure.

Driving Forces

Driving forces change pressure relationships and create airflow. Common driving forces are identified in the table below.

Major Driving Force	Effect
Wind	Positive pressure is created on the windward side causing infiltration, and negative pressure on the leeward side causing exfiltration, though wind direction can be varied due to surrounding structures.
Stack Effect	When the air inside is warmer than outside, it rises, sometimes creating a column of rising air -- up stairwells, elevator shafts, vertical pipe chases etc. This buoyant force of the air results in positive pressure on the higher floors and negative pressure on the lower floors and a neutral pressure plane somewhere between.
HVAC/Fans	Fans are designed to push air in a directional flow and create positive pressure in front, and negative pressure behind the fan

Flues and Exhaust	Exhausted air from a building will reduce the building air pressure relative to the outdoors. Air exhausted will be replaced either through infiltration or through planned outdoor air intake vent.
Elevators	The pumping action of a moving elevator can push air out of or draw air into the elevator shaft as it moves.

Common Airflow Pathways

Contaminants travel along pathways - sometimes over great distances. Pathways may lead from an indoor source to an indoor location or from an outdoor source to an indoor location.

The location experiencing a pollution problem may be close by, in the same or an adjacent area, but it may be a great distance from, and/or on a different floor from a contaminant source.

Knowledge of common pathways helps to track down the source and/or prevent contaminants from reaching building occupants.

Common Airflow Pathways for Pollutants

Common Pathway	Comment
Indoors	
• Stairwell • Elevator shaft • Vertical electrical or plumbing chases	The stack effect brings about air flow by drawing air toward these chases on the lower floors and away from these chases on the higher floors, affecting the flow of contaminants.
Receptacles, outlets, openings	Contaminants can easily enter and exit building cavities and thereby move from space to space.
Duct or plenum	Contaminants are commonly carried by the HVAC system throughout the occupied spaces.
Duct or plenum leakage	Duct leakage accounts for significant unplanned air flow and energy loss in buildings.
Flue or exhaust leakage	Leaks from sanitary exhausts or combustion flues can cause serious health problems
Room spaces	Air and contaminants move within a room or through doors and corridors to adjoining spaces
Outdoors to Indoors	
Indoor air intake	Polluted outdoor air or exhaust air can enter the building through the air intake
Windows/doors Cracks and crevices	A negatively pressurized building will draw air and outside pollutants into the building through any available opening
Substructures and slab penetrations	Radon and other soil gases and moisture-laden air or microbial contaminated air often travel through crawlspaces and other substructures into the building.

Ventilation

Ventilation can be used to either exhaust pollutants from a fixed source, or dilute pollutants from all sources within a space.

Exhaust Ventilation

Ideally, exhaust airflow should be sufficient to draw pollutants from the source into the exhaust and away from occupants. The source should be located between the exhaust and the occupants. Rooms with major sources should be under negative pressure relative to the surrounding spaces. Some sources, such as cooking stoves and laboratory benches, may require exhaust hoods. Also see Exhaust Systems.

Dilution Ventilation

Contaminants from area sources such as, people, building materials, office equipment, are diluted with outdoor air from natural or mechanical ventilation. Ventilation systems should be operated to provide sufficient outdoor air ventilation. Reducing outdoor air ventilation rates below required levels saves little energy and is not advisable. If capacity is available, outdoor air ventilation rates should meet applicable standards under all operating conditions. Problems with reduced outdoor air during part-load in certain VAV systems should be addressed.

Ventilation Measurements

Measurement instruments and techniques, which are generally available to building personnel, can be extremely useful in assessing the performance of the right ventilation system for both exhausting and diluting pollutants. Useful measuring tools include:

- Smoke tube to measure airflow
- Flow hood to measure air volume
- Velocity meter to measure air velocity
- Measuring carbon dioxide to estimate the percentage of outdoor air or to generally evaluate outdoor air ventilation

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: Heating, Ventilation, and Air-conditioning (HVAC)

This module identifies elements of the heating, ventilating, and air conditioning (HVAC) system that are important to IAQ, as well as information important to developing protocols for the operating set points and schedules consistent with good IAQ performance.

Contents

- **Heating, Ventilation and Air Conditioning (HVAC) System**
  - Ventilation Systems
  - Constant Volume (CV) Systems
  - Variable Air Volume (VAV) Systems
  - Economizer
- **HVAC Components**
  - Coils and Drain Pans
  - Humidification and Dehumidification Equipment
  - Outdoor Air Dampers
  - Air Filters
  - Ducts
  - Exhaust Systems
  - Return Air Plenum
  - VAV Boxes
  - Cooling Towers
  - Boilers
- **HVAC Operations and Standards**
  - ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*
  - Existing Buildings
  - Multiple Space Systems
  - Intermittent Occupancy
  - Pre-Occupancy Purge
  - Control of Temperature and Relative Humidity
    - ASHRAE Thermal Comfort Requirements
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I-BEAM Text Modules

- Fundamentals of IAQ in Buildings
- **Heating, Ventilation, and Air-conditioning (HVAC)**
- IAQ Maintenance and Housekeeping Programs
- Indoor Air Quality and Energy Efficiency
- Diagnosing and Solving Problems
- Renovation and New Construction
- Managing for Indoor Air Quality
- IAQ Budgets and Accounts

- Overview of I-BEAM
- Overview of Text Modules
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- IAQ Budgets and Accounts
- I-BEAM Forms

Heating, Ventilation, and Air-conditioning (HVAC) (PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

Heating, Ventilation, and Air Conditioning (HVAC) Systems

Ventilation Systems

There are significant spatial and seasonal variations in the volume of air delivered by most HVAC systems. HVAC Operators must understand the variations to know how to provide occupants with adequate outdoor air in all spaces throughout the year. The ventilation features most important to IAQ are the way in which supply air volume is controlled, and the way in which outdoor air delivery is controlled.

In most HVAC systems a portion of ventilation air supplied to occupied spaces is outdoor air and a portion is recirculated air. The total volume of air is important for two reasons:

- Air movement contributes to thermal comfort. The lack of air movement can create a sensation of hot/stuffy air.
- In many VAV systems (see below), outdoor air is a constant fraction of the total supply air. Thus, the total volume of outdoor air depends on both the outdoor air fraction, and the supply air volume.

There are **two major types of HVAC systems** based upon the use of airflow to control temperature -- the Constant Volume (CV) system, and the Variable Air Volume (VAV) system.

Constant Volume (CV) Systems

In a Constant Volume (CV) ventilation system, variations in the thermal requirements of a space are satisfied by varying the temperature of a constant volume of air delivered to the space. A constant fraction of outdoor air will mean that a constant volume of outdoor air will be delivered to occupied spaces. This volume can be set to satisfy applicable ventilation standards. CV systems are less energy efficient than VAV systems, but controls for outdoor air delivery are simpler to manage.

Variable Air Volume (VAV) Systems

In a Variable Air Volume (VAV) ventilation system, variations in the thermal requirements of a space are satisfied by varying the volume of air that is delivered to the space at a constant temperature. VAV systems reduce HVAC energy cost by 10-20% over CV systems but complicate the delivery of outdoor air. If the fraction of outdoor air is constant, the total volume of outdoor air will be reduced as the supply air volume is reduced. An inadequate outdoor air fraction, combined with an inadequate VAV box minimum setting, may result in inadequate outdoor air flow to occupant spaces. This would occur during part-load conditions. VAV systems also complicate pressure relationships in the building and make testing, adjusting, and balancing more difficult.

Most of the year, the volume of outside air may be reduced to about a third of the outdoor air volume at design load. This could result in indoor air quality problems. Separate controls to insure adequate outside air year round do not increase energy costs. Some new VAV systems incorporate these controls.

Economizer

Economizers are controls of the outdoor air designed to save energy by using cool outside air as a means of cooling the indoor space. When the enthalpy of the outside air is less than the enthalpy of the recirculating air, conditioning the outside air is more energy efficient than conditioning recirculating air.

Economizers can reduce HVAC energy costs in cold and temperate climates while potentially improving IAQ, but are not appropriate in hot and humid climates.

HVAC Components

Many HVAC components are particularly important to maintaining good IAQ. Tips for optimum functioning are listed below.

Coils and Drain Pans

- Malfunctioning coils, including dirty coils, can waste energy and cause thermal discomfort. Leaky valves that allow hot or chilled water through the coil when there is no demand waste energy and create thermal discomfort.
- Cooling coils dehumidify the air and cause condensate water to drip into a drain pan and exit via a deep seal trap.
- Standing water will accumulate if the drain pan is not properly designed and maintained, creating a microbial habitat. Proper sloping and frequent cleaning of the drain pans is essential to good indoor air quality.

Humidification and Dehumidification Equipment

- Potable water rather than boiler water should be used as a source of steam to avoid contaminating the indoor air with boiler treatment chemicals.
- Wet surfaces should be properly drained and periodically treated as necessary to prevent microbial growth.
- Duct linings should not be allowed to become moist from water spray.

Outdoor Air Dampers

Screens and grilles can become obstructed. Remove obstructions, check connections, and otherwise insure that dampers are operating to bring in sufficient outdoor air to meet design-level requirements under all operating conditions.

Air Filters

- Use filters to remove particles from the air stream.
- Filters should be replaced on a regular basis, on the basis of pressure drop across the filter, or on a scheduled basis.
- Fans should be shut off when changing the filter to prevent contamination of the air.
- Filters should fit tightly in the filter housing.
- Low efficiency filters (ASHRAE Dust Spot rating of 10%-20%), if loaded to excess, will become deformed and even "blow out", leading to clogged coils, dirty ducts, reduced indoor air quality and greater energy use.
- Higher efficiency filters are often recommended as a cost-effective means of improving IAQ performance while minimizing energy consumption. Filtration efficiency should be matched to equipment capabilities and expected airflows.

Ducts

A small amount of dust on duct surfaces is normal. Parts of the duct susceptible to contamination include areas with restricted airflow, duct lining, or areas of moisture or condensation. Problems with biological pollutants can be prevented by:

- Minimizing dust and dirt build-up (especially during construction or renovation)
- Promptly repairing leaks and water damage
- Keeping system components dry that should be dry

- Cleaning components such as coils and drip pans
- Good filter maintenance
- Good housekeeping in occupied spaces.

Duct leakage can cause or exacerbate air quality problems and waste energy. Sealed duct systems with a leakage rate of less than 3% will usually have a superior life cycle cost analysis and reduce problems associated with leaky ductwork. Common problems include:

- Leaks around loose fitting joints.
- Leaks around light Troffer-type diffusers at the diffuser light fixture interface when installed in the return plenum.
- Leaks in return ducts in unconditioned spaces or underground can draw contaminants from these spaces into the supply air system.

Exhaust Systems

In general, slightly more outdoor air should be brought into the building than the exhaust air and relief air of the HVAC system. This will insure that the building remains under slight positive pressure.

- Exhaust intake should be located as close to the source as possible.
- Fan should draw sufficient air to keep the room in which the exhaust is located under negative pressure relative to the surrounding spaces, including wall cavities and plenums.
- Air should flow into, but not out of, the exhaust area, which may require louvered panels in doors or walls to provide an unobstructed pathway for replacement air.
- The integrity of walls and ceilings of rooms to be exhausted must be well maintained to prevent contaminated air from escaping into the return air plenum.
- Provisions must be made for replacing all air exhausted out of the building with make-up outside air.

Return Air Plenum

- Space above the ceiling tiles is often used as a return air plenum.
- Strictly follow code which restricts material and supplies in the plenum to prevent contamination and insure that airflow is not interrupted. Remove all dirt and debris from construction activity.
- All exhaust systems passing through the plenum must be rigorously maintained to prevent leaks, and no exhaust should be released into the plenum.
- Avoid condensation on pipes in plenum area. Moisture creates a habitat for microbial growth.

VAV Boxes

In a VAV system, a VAV box in the occupied space regulates the amount of supply air delivered to the space, based on the thermal needs of the space. Malfunctioning VAV boxes can result in thermal discomfort and fail to prevent buildup of indoor air contaminants. It is important to insure that VAV box minimum settings (e.g., 30% of peak flow) combined with the outdoor air fraction provide enough supply air so that sufficient outdoor air enters the space at partial loads.

Cooling Towers

Water is a convenient incubator for microbial growth, with potentially fatal consequences, such as Legionnaires Disease, for building occupants. Periodically monitoring water quality and chemical treatment to prevent microbial growth is essential. Physical cleaning to prevent sediment accumulation and installation of drift eliminators may also be necessary.

Boilers

Fossil fuel combustion boilers provide the potential for contamination with carbon monoxide or other combustion by-products.

- Maintain gaskets and breaching to prevent carbon monoxide from escaping.
- Maintain the room in which the boiler is located under sufficient positive pressure relative to the outside to prevent back drafting of flue gases. Back drafting occurs when flue gases fail to be drawn up the the flue and spill out into the room. Provide combustion air directly from the outside to prevent back drafting. A smoke tube can be used to check for back drafting.
- Provide high enough exhaust stacks to prevent re-entrainment into the building, and maintain fuel lines to prevent leaks.

HVAC Operations and Standards

ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*

ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*, is the generally-accepted standard for commercial buildings in the United States. Table 2 in that Standard provides ventilation requirements for various spaces.

Table 2.1 Selected Ventilation Recommendations

	Occupancy		

Application		(people / 1000 ft^2)	Cfm / person	Cfm / ft^2
Food and Beverage Service	Dining rooms Cafeteria, fast food Bars, cocktail lounges Kitchen (cooking)	70 100 100 20	20 20 30 15	-
Offices	Office space Reception areas Conference rooms	7 60 50	20 15 20	-
Public Spaces	Smoking lounge Elevator	70 -	60 -	- 1.00
Retail Stores, Sales Floors, Showroom Floors	Basement and street Upper floors Malls and Arcades Smoking lounge	30 20 20 70	- - - 60	0.30 0.20 0.20 -
Sports and Amusement	Spectator areas Game rooms Playing floors Ballrooms and discos	150 70 30 100	15 25 20 25	-
Theaters	Lobbies Auditorium	150 150	20 15	-
Education	Classrooms Music rooms Libraries Auditoriums	50 50 20 150	15 15 15 15	-
Hotels, Motels, Resorts, Dormitories	Bedrooms Living rooms Lobbies Conference rooms Assembly rooms	- - 30 50 120	- - 15 20 15	30 cfm/room 30 cfm/room - - -

Since indoor air quality depends on many factors, including source strengths, moisture control, and thermal parameters, these ventilation requirements cannot guarantee good indoor air quality, but meeting these requirements is a sign of managing for good indoor air quality, where unusual countercurrents or sources are present, they should be controlled at the source.

The outdoor air flow requirements of ASHRAE Standard 62-1999 are usually specified as cfm/occupant. The occupancy value should be the actual occupancy of the space or, for new buildings, the design occupancy. The total outdoor airflow is given by:

OA = (cfm / occupant) X (number of occupants)

The required outdoor air fraction is the fraction of outdoor air required so that the total outdoor airflow in the supply air is sufficient to provide the amount of outdoor air per occupant required in the Standard. However, the outdoor air fraction in the supply air is NOT equivalent to the outdoor air requirements specified in Table 2 of the Standard. That is, if the Standard requires 20 cfm of outdoor air per occupant, that does NOT mean that the outdoor air fraction should be 20%. The best way to determine outdoor air flow is to measure it.

For VAV systems, the outdoor air fraction will change as the supply air volume changes in response to changing loads. In the case of control systems that provide a constant outdoor air fraction and meet outdoor air requirements at design (peak) loads, outdoor airflow into the building at part-load will reduce the outdoor air to between one-half to two-thirds the design flow. This may be a cause of indoor air quality complaints. Manufacturers offer controls for VAV systems that can vary the outdoor air fraction to satisfy Table 2 of the Standard under all load conditions.

Existing Buildings

For existing buildings, the HVAC system should be operated to meet, at a minimum, operating parameters for providing thermal comfort and outdoor air ventilation flow as specified in design documents. However, provided that capacity is available in older buildings, it is a good idea to go beyond design requirements where feasible, and program the operating controls to satisfy the outdoor air ventilation requirements of ASHRAE 62-1999.

Should the outdoor air flow rates of ASHRAE Standard 62-1999 exceed the system's design flow rates, a careful load analysis at these elevated flow rates should be undertaken to insure that the system has sufficient capacity for the added load at peak load conditions. Failure to perform such an analysis could result in deterioration of IAQ and/or coil freezing during extreme weather conditions.

Multiple Space Systems

In multiple zone systems, different spaces within a system will call for different outdoor air fractions. This is because loads (and therefore supply air requirement) are different, and/or occupant densities (and therefore outdoor air requirements) are different.

For multiple space systems, even when the total outdoor air volume equals the sum of the requirements of individual spaces, many of the spaces may be under-ventilated most of the time. For example, even with uniform occupant densities, systems servicing both the perimeter and core zones will leave the core zone with only a third to a half of the outdoor air required by Table 2 throughout the year, while the south zone will be over ventilated most of the time. This may result in indoor air quality complaints.

Thus, multiple space systems require higher overall outdoor air fractions. This is calculated by considering the outdoor air fraction required to satisfy the critical zone. The critical zone is the zone with the highest outdoor air fraction requirement. The calculation for the outdoor air fraction required at the air handler is as follows:

Y=X / (1 + X - Z)

where:

Y = adjusted outdoor air fraction required for the system
X = unadjusted outdoor air fraction for the system calculated from the Standard
Z = outdoor air fraction in the critical zone

Unfortunately, both the critical zone and the outdoor air fractions will be different at full load and at part-load. Some manufactures do offer DDC/VAV control systems that dynamically calculate the correct outdoor air fraction at the air handler as the space load requirement changes.

Short-circuiting of the supply air into a space directly to the exhaust should be avoided (ASHRAE, 1989, Section 6.1.3.3). If short-circuiting does occur, building engineers may wish to increase the outdoor airflow rate to insure good indoor air quality.

Intermittent Occupancy

Conference rooms or training spaces often have intermittent occupancies. Provided that peak occupancies are of less than three hours duration, the Standard allows that the outdoor air requirement of the space be calculated on the basis of the average occupancy. However, the outdoor air may never be below one-half the maximum. (ASHRAE, 1989, Section 6.1.3.4)

Alternatively, ventilation in these spaces may be increased and decreased as occupancy increases or decreases, but even when unoccupied, the outdoor air ventilation should never be less than necessary to dilute building related contaminants. (ASHRAE, 1989, Section 6.1.3.1)

Pre-Occupancy Purge

Delivery of outdoor air should precede occupancy to purge the air of contaminants that built up prior to occupancy. (ASHRAE, 1989, Section 6.1.3.4)

Control of Temperature and Relative Humidity

The thermal requirements of the space are designed to provide thermal comfort to occupants during all hours of occupancy. Requirements for temperature, relative humidity, and air movement during all seasons should be established and monitored to insure that thermal comfort requirements are met.

ASHRAE Thermal Comfort Requirements

ASHRAE Standard 55-1992, *Thermal Environmental Conditions for Human Occupancy*, identifies many factors that influence thermal comfort and the perception of thermal conditions. Among them are temperature, radiation, humidity, air movement, vertical and horizontal temperature differences, temperature drift, personal activity and clothing.

As a practical matter, maintaining a building within the following ranges of temperature and relative humidity will satisfy thermal comfort requirements of this standard in most cases.

Table 2.2 Acceptable Temperature and Humidity Ranges

Measurement Type	Winter	Summer
Dry Bulb at 30% RH	68.5°F - 76.0°F	74.0°F - 80.0°F
Dry Bulb at 50% RH	68.5°F - 74.5°F	73.0°F - 79.0°F
Wet bulb maximum	64°F	68°F

Relative humidity *	30% - 60%	30% - 60%
* Upper bound of 50% RH will also control dust mites.		

Humidity and Microbial Growth

In addition to thermal comfort, the control of relative humidity is important to limit the growth of microorganisms such as mold and dust mites. To control microorganisms, it is best to keep relative humidity below 60% (to control mold) and 50% (to control dust mites) at all times, including unoccupied hours. High relative humidity can foster proliferation of mold and dust mites. See also www.epa.gov/mold

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: IAQ Maintenance and Housekeeping Programs

Good preventive maintenance and housekeeping practices are at the core of establishing and maintaining good indoor air quality in buildings. In this module, we describe the essential elements of preventive maintenance and housekeeping programs and describe their relationship to IAQ.

This module contains detailed maintenance and housekeeping schedules which the user can modify to satisfy individual building requirements, or to establish an IAQ maintenance and housekeeping budget.

- **IAQ Maintenance Program**
  - Relation of PM to IAQ
  - Economics of Good PM
  - Types of Preventive Maintenance
    - Scheduled Maintenance
    - Unscheduled Maintenance
  - Elements of a PM System
    - Administrative Method
    - Files and Records
    - PM Charts and Work orders
    - Master Schedule
  - How to Set Up a PM System
- **Housekeeping Program**
  - General
  - Economics of IAQ Housekeeping Program
  - Stewardship Principles
  - Elements of a Housekeeping Program
  - Principles to Cleaning for Indoor Air Quality
    - Keep Dirt Out
    - Use Maximum Extraction, Minimum Polluting Equipment and Methods
    - Choose Low Polluting Products

I-BEAM Text Modules

- Fundamentals of IAQ in Buildings
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IAQ Maintenance and Housekeeping Programs (PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

    - Thoroughly Dry Wet Carpet or Other Porous Material After Spills or Cleaning
    - Properly Mix and Store Housekeeping Products in a Ventilated Room or Closet
    - Train Housekeeping Personnel
    - Scrutinize Contractors
    - Monitor Results

- Establishing a Housekeeping Program
    - Survey the Building
    - Establish Areas Requiring Differential Attention
    - Develop a Housekeeping Program

IAQ Maintenance Program
(see also IAQ Forms)

Relation of Preventive Maintenance (PM) to IAQ

A PM program provides the care to all building mechanical systems and components that keeps them operating at peak performance according to manufacturer's specifications. An effective preventive maintenance (PM) program is the most important tool to preventing IAQ problems.

- Lack of effective PM is one of the biggest causes of IAQ problems.
- Facilities with effective PM programs generally have fewer problems.
- You cannot quickly diagnose and solve many IAQ problems without an effective PM program because you won't have the system knowledge and records to do so.
- Should IAQ problems result in legal action, your PM records may prove good faith efforts to control IAQ.

Economics of Good PM

PM is ***one of the most cost effective tools*** available for increasing energy efficiency in most buildings. For example:

- All equipment works at peak efficiency according to design.
- Clean filters and ductwork reduce workload on fans.
- Clean heating and cooling coils transfer temperature more efficiently.
- Controls operate to provide service when needed, and to shut down when not needed.

PM reduces problems and complaints and the time and expense of responding to them.

- Less time and expense responding to complaints.
- Reduced liability exposure.

PM extends equipment life and results in fewer unscheduled repairs.

Types of Preventive Maintenance

Scheduled Maintenance

Scheduled maintenance is planned and scheduled through the PM system and controlled through PM work orders. Scheduled maintenance is critical to avoiding IAQ problems. Potential problems are discovered through the PM system and fixed before they become IAQ issues that require an IAQ investigation (see Forms

B2).

Unscheduled Maintenance

Unscheduled maintenance activities are those that occur outside of the regularly scheduled maintenance program. IAQ problems occur most readily in buildings where most equipment is maintained only when it breaks down. A good IAQ program will avoid IAQ problems from equipment failure by maintaining a good PM program.

Unscheduled maintenance will also occur as a result of a PM inspection which identifies repairs which can not be completed during the inspection, and establishes a repair work order. When repairs are completed, information about the repair, including what was done, what supplies were used, what caused the problem, and how long the job took, is entered into the PM information system.

Elements of a PM System

Administrative Method

The administrative method of a PM system is its organizing tool in which records are kept. This may be a manual using file folders and three ring binders, or a computer-based system. Both systems are commercially available.

Files and Records

The main files and records in a PM program are:

- **A master equipment list**: Contains serial numbers, spare parts required, parts suppliers, and all equipment specifications. The equipment inventory enables the ordering of all parts and services directly from the PM equipment files.

- **An equipment history record file**: Contains a historical record of the installation and all work performed on each piece of equipment.

- **Operating Manuals, Manufacturer's Data, and System Prints**: This set of files should include:
    - Updated facility design blueprints
    - Chronological set of as-built blueprints of mechanical, electrical and plumbing systems. Control blueprints should include a written description of how the system operates
    - Manufacturers specifications for all system controls, including catalogs
    - Schematic duct layout from last testing and balancing showing ductwork, fans, outlets, etc.
    - Air balancing reports and air flow specifications
    - Building commissioning reports
    - A print for each floor detailing all occupant activities and room layouts

PM Charts and Work orders

Each piece of equipment will have a PM chart that identifies all the scheduled maintenance on that equipment throughout the year. A PM work order is a form or "ticket" that is designation of tasks to be performed on a piece of equipment. For example, if the PM chart identifies a set of tasks to be performed every quarter, there will be 4 PM work orders issued throughout the year.

PM work orders include:

- Inspections for unusual conditions like excessive noise and heat
- Inspections for leaks, rust, dirt and mechanical problems
- Regular and careful lubrication
- Mechanical and electrical adjustments
- HVAC testing and balancing
- Operational checks
- Parts replacement
- Coil cleaning and filter replacement

Tasks associated with these work orders may be scheduled daily, weekly, monthly, quarterly, biannually or annually. The schedule is indicated on the PM chart.

Repair Work orders are created as unscheduled maintenance when equipment fails or when repair needs of more than a few hours are noticed during a PM inspection. For example:

- Periodically, maintenance personnel work from a PM work order and check the general operation of all HVAC fans. They inspect belt tension, damper operation, filter cleanliness, and all mechanical supports like motor mounts. They tighten the belts, change the filters, and make other minor corrections as needed during their inspection. They note other repairs needed. These are handled as unscheduled maintenance through a repair work order.

Master Schedule

A master schedule identifies all PM tasks and identifies the frequency (number of times per year) with which the task is performed. See an I-BEAM example for PM schedules for HVAC Maintenance and General Maintenance.

How to Set Up a PM System

Take the following steps to set up a PM system:

- Select an administrative system.
- Survey and develop an inventory of all equipment in the building.
- Record the condition of each piece of equipment, and develop work orders for their repair. The objective is to bring each piece of equipment up to peak operating performance.
- Establish a master equipment list and an equipment history record file.
- Organize master files of operating manuals, manufacturer's data, and system prints. Review and update. Create working copies of these files.
- Using operating manuals and manufacturer's specifications as a guide, develop PM charts for each piece of equipment.
- From the PM charts, develop PM work orders.
- Organize all work orders chronologically into a Master Schedule.
- Adjust the schedule to insure an even workload of basic PM scheduled evenly throughout the year.

- Leave time for unscheduled maintenance.
- Your PM system is now in place.

Housekeeping Program

General

Sources of dirt and dust can be internal or external. Internal sources include human and animal dander, the breakdown of materials and furnishings, plants, building activities such as cooking and printing, smoking, and cleaning materials such as powders, waxes, and solvents. External sources include dirt brought in from pedestrian traffic, diesel or bus exhaust, as well as airborne dust and chemical contaminants outside the building.

Housekeeping both cleans and has the potential to pollute the indoor environment. This is why the choice of materials and methods is crucial to indoor air quality.

A housekeeping program is more than just a cleaning program. It involves:

- Actions to **prevent dirt** from entering the environment as well as its removal once it is there.
- **Choices of products and methods** that minimize the introduction of pollutants into the environments that the housekeeping program is designed to clean.
- Tasks designed for **health and safety** as well as tasks designed for appearance.
- **Training, negotiating, and monitoring** performance.

Economics of IAQ Housekeeping Program

There is little difference in cost between a standard cleaning program and one which is designed to improve IAQ. Some elements of an IAQ housekeeping program increase costs and some decrease costs. Hence, the costs are generally the same. However, in the long run, the costs of an IAQ housekeeping program are likely to be lower for many reasons.

- The IAQ program requires more diligent choice of material and methods, and training which increases cleaning costs.
- The IAQ program pays attention to methods of keeping dirt out and preventing cleaning problems. This decreases cleaning costs.
- The IAQ program extends the life of carpet and furnishings. This decrease in cost is directly attributable to the improved cleaning regime.
- The principles for cleaning for indoor air quality, while not substantially different, can make a large difference in the indoor environment.

Stewardship Principles

(see ASTM Standard E1971-98: Standard Guide for Stewardship for Cleaning of Commercial and Institutional Buildings)

Underlying any housekeeping program should be a set of principles that define the way in which the housekeeping program will be structured and managed. These principles should reflect a recognition that housekeeping services are designed to improve the indoor environment, but have the capacity to degrade it if not performed properly. Useful stewardship principles might include:

- **Clean for health and safety first, not just for appearance**: Appearances can be deceiving. Dirt, film, grime and other contaminants that can't be seen should nevertheless be cleaned because pollution will migrate and diminish indoor air quality in all parts of the building.

- **Protect workers from hazardous working conditions**: Such protections include providing adequate ventilation, personal protective equipment, proper labeling, and proper mixing areas and procedures.
- **Encourage participation and communication**: Cleaning personnel, occupants, and contractors should participate in the development, implementation, and refinement of the program. Occupants should understand how their actions, such as food debris, impact the indoor environment and the cleaning process.
- **Invest in people and equipment**: Cleaning personnel should be well trained. Equipment should be capable of performing the tasks in manner that protects the indoor environment.
- **Recognize the impact of cleaning wastes on the outdoor environment**: Proper handling and disposal of medical waste according to applicable codes and regulations is important. Regulations governing proper disposal of non-medical hazardous materials such as chemical cleaners should also be followed.

Elements of a Housekeeping Program

A housekeeping program is a process involving more than just cleaning the building. Elements of the program are:

- Methods to reduce the introduction of dirt into the environment to be cleaned
- Identification of the cleaning tasks and performance requirements
- Definition of (and periodic reassessment of) cleaning products, equipment, and procedures
- Training of cleaning personnel
- Proper mixing, disposal and storage methods
- Provisions to protect workers from housekeeping emissions
- Provisions for timing certain tasks to minimize occupant exposures
- Inspection and monitoring of the cleaning process

Principles to Cleaning for Indoor Air Quality

Keep Dirt Out

- Clean outside the building, especially near entry ways, so that less dirt is traveled into the building.
- Use barrier mats (walk off mats) on all entry ways, including pedestrian entrances, loading docks, receiving areas, freight entrances, garages into the building. The barrier mats are designed to trap dirt and keep it out of the building. Barrier mats should be long enough that everyone entering the building should be taking five full steps on the mat.
- Use deep and frequent cleaning of carpet in heavily used areas. Especially in entryways, as dirt accumulates it migrates further into the building. These areas should receive thorough cleaning daily, or more frequently as needed.
- Keep dirt and other pollutants away from outdoor air intake.
- Restrict smoking.
- Isolate interior polluting sources using exhaust fans and pressure control.
- Upgrade HVAC filters and change regularly.

Use Maximum Extraction, Minimum Polluting Equipment and Methods

- Deep clean carpets at regular intervals.
- Thoroughly vacuum using high efficiency filtration bags.
- Use only floor machines with vacuum capability.
- Avoid carpet treatments with sticky residues.
- Use lint free dusting cloths. Avoid dusters that don’t capture dust (e.g., feather dusters).
- Cover top of dust mops with dust cloths to avoid passing dust over the mop.

- Avoid aerosol sprays.
- Use toggle top chemical dispensers or trigger spray directly onto cloth.
- Vacuum dust skirts on floor machines.

Choose Low Polluting Products

- Use MSDS sheets to select “environmentally preferable” products. Minimize volatile organic compounds.
- Choose products with a moderate PH (between 5 and 9). Minimize use of ammonia, chlorine, and volatile acids, and other products that are corrosive, or reactive with other cleaning products.
- Minimize use of aerosols or particle cleaners as they may become airborne.

Thoroughly Dry Wet Carpet or Other Porous Material After Spills or Cleaning

- Wet or damp materials are a breeding ground for mold.
- Thoroughly dry material after a water spill immediately. If not dried within 24 hours, the material may have to be discarded.
- Thoroughly dry after wet process cleaning.

Properly Mix and Store Housekeeping Products in a Ventilated Room or Closet

- Follow protocol for storing any chemical product in room or closet exhausted to the outside and under negative pressure, with no opening to the return air plenum.

Train Housekeeping Personnel

- Train all housekeeping personnel before they are allowed to participate in the cleaning operation. One improper application of a chemical product, or failure to use dust free wipe can contaminate a whole environment and create problems.
- Training should include developing an appreciation for the role the person plays in creating and maintaining a healthy environment in addition to training on equipment, materials and methods.

Scrutinize Contractors

- Many buildings will use a housecleaning contractor.
- Negotiate contracts laying forth the principles outlined in I-BEAM to insure that the housekeeping plan supports IAQ in the building.

Monitor Results

- Monitor the results of housekeeping tasks to insure that the building is kept clean as required.
- Monitor the actual performance of tasks to insure that the tasks are performed as required.
- Monitor the complaints and reactions of building occupants.
- Do not tolerate deviations from good practices. Good indoor air quality depends on diligence in following these performance guidelines.
- Keep good records of what is cleaned, how it is cleaned, and when it is cleaned.

Establishing a Housekeeping Program

Survey the Building

A cleaning survey involves an assessment of sources of dirt, and assessment of methods to prevent dirt from entering the building, and an assessment of cleaning needs of individual spaces. Particular attention in the survey should be given to sources of dirt and areas of dirt accumulation. For example:

- Assess dirt potential of pedestrian traffic, loading docks, receiving areas, and garages.
- Assess surrounding vegetation, pollen, and proper drainage around building.
- Assess interior sources such as printing and copying rooms, kitchens, eating areas, and smoking, trash needs, storage areas, carpets and furnishings, ceiling tiles.
- Assess dirt accumulation areas such as horizontal surfaces, corners and edges, furniture, high surfaces, windows and blinds.

Establish Areas Requiring Differential Attention

From this survey, you will be able to assess ways to prevent dirt and pollution from entering the building space, and then to assess differential cleaning needs of each part of the building. Different parts of the building will require different types of cleaning. Areas requiring differential attention will include:

- Entryways and lobbies
- Bathrooms
- Hallways and corridors
- Kitchens and cafeterias
- Offices

Develop a Housekeeping Program

From the needs identified in the survey, develop a housekeeping program including all the elements recommended by I-BEAM and based on the principles of stewardship. Compare the housekeeping tasks with I-BEAM's example task list below and refine as appropriate.

1. Print out and/or view examples of **IAQ Maintenance Tasks** which includes inspection/actions and possible frequency time between tasks.
   - Operations and Maintenance: **I-BEAM Form B2 - Periodic IAQ Maintenance Inspection** (PDF, 13 pp, 52KB)
2. Print out and/or view examples of IAQ Housekeeping Tasks by activity. Source: Specifications for Superior Service Building - Office Building Cleaning Operations in North America, Building Owners and Managers Association International, 1990 - Page 61-63.
   - **Examples of IAQ Housekeeping Tasks** (PDF, 4 pp, 24KB)

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: Indoor Air Quality and Energy Efficiency

Contents

- **Energy Cost and IAQ Performance of Ventilation Systems and Controls**
- **Energy Retrofit Measures and IAQ**
  - Retrofit Measures Compatible with IAQ
  - Retrofit Measures That Are Incompatible With IAQ
- **Operational Measures for Energy and IAQ**
  - Operational Measures That Are Compatible With IAQ
  - IAQ Incompatible Operational Measures
- **International Performance Measurement and Verification Protocol (IPMVP)**
- **Calculating Energy Saving Potential of Upgrades**

I-BEAM Text Modules

- Fundamentals of IAQ in Buildings
- Heating, Ventilation, and Air-conditioning (HVAC)
- IAQ Maintenance and Housekeeping Programs
- **Indoor Air Quality and Energy Efficiency**
- Diagnosing and Solving Problems
- Renovation and New Construction
- Managing for Indoor Air Quality
- IAQ Budgets and Accounts

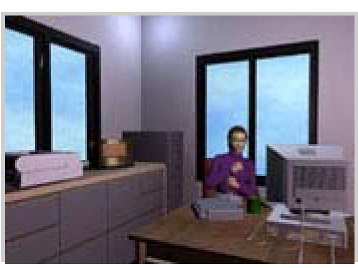
- Overview of I-BEAM
- Overview of Text Modules
- Overview of Visual Reference Modules
- IAQ Budgets and Accounts
- I-BEAM Forms

Indoor Air Quality and Energy Efficiency (PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

Energy Cost and IAQ Performance of Ventilation Systems and Controls



In 1999, EPA completed an extensive modeling study to assess the compatibilities and trade-offs between energy, indoor air quality, and thermal comfort objectives for HVAC systems and to help formulate strategies to simultaneously achieve superior performance on each objective. Much was learned as a result of this effort. The entire documentation of the study is contained in 7 individual reports plus an executive summary. All of the reports and the executive summary are available (See Energy Cost and IAQ Performance of Ventilation Systems and Controls Study EPA-4-2-S-01-001, January 2000)

Variations of Constant Volume (CV) and Variable Air Volume (VAV) systems were modeled in three different climates-hot and humid (Miami), temperate (Washington D.C.), and cold (Minneapolis) in an office building, school, and auditorium. Some of the key results are summarized below.

Energy and IAQ Compatibilities and Trade-Offs

How Did the Performance of CV and VAV Systems and Alternative Outdoor Air Control Strategies Compare? (Large Office Building)

- **Key Result: VAV systems saved energy**

  Explanation: The variable air volume systems provided $0.10 - $0.20 energy savings per square foot over constant volume systems modeled for a savings of 10% to 21% of HVAC energy cost. Since the modeled CV system is much more energy efficient than other CV systems, the results tend to underestimate the advantages of conversion from CV to VAV systems.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B

- **Key Result: VAV with fixed outdoor air fractions caused outdoor air flow problems**

  Explanation: VAV systems may require a different outdoor air control strategy at the air handler to maintain adequate outside air for indoor air quality than the constant volume predecessor. If the fixed outdoor damper strategy of the CV system, which is commonly used in the VAV systems, results in a fixed outdoor air fraction, the outdoor air delivery rate at the air handler may be cut to about one half to two thirds the design level during most of the year.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B

- **Key Result: Core zones received significantly less air than perimeter zones**

  Explanation: Both CV and VAV systems provided an unequal distribution of supply air and outdoor air to zones. The south zone received the highest and the core zone received the least outdoor air. The core zone received only about two thirds of the building average outdoor air flow.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: Core zones in VAV systems with a fixed outdoor air fraction received very little outdoor air**

  Explanation: The VAV system with fixed outdoor air fraction diminished the outdoor air delivery to the core zone to only about one third of the design level.. Even though the VAV with fixed outdoor air fraction is designed to deliver 20 cfm of outdoor air per occupant, the core zone received only 6-8 cfm per occupant, and only 2-3 cfm per occupant for a design level of 5 cfm per occupant. In some cases, this could contribute to higher indoor air quality complaint rates in the core relative to the perimeter zones.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control

Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: VAV with constant outdoor air control showed better outdoor air delivery without any meaningful energy penalty**

Explanation: A VAV system with an outdoor air control strategy that maintains the design outdoor air flow at the air handler all year round had slightly lower energy cost in the cold climate, and slightly more energy cost in the hot and humid climate. It is therefore comparable in energy cost, but preferred for indoor air quality.

- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B
- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: Economizers on VAV systems may be advantageous for both indoor air quality and energy in cold and temperate climates**

Explanation: By increasing the outdoor air flow when the outside air temperature (or enthalpy) is less than the return air temperature (or enthalpy), economizers can reduce cooling energy costs. For office buildings, economizers may operate to provide free cooling even at winter temperatures (e.g., at zero degrees Fahrenheit), provided that coils are sufficiently protected from freezing. Temperature economizers may need some mechanism to control humidity during warm weather. For the office building, energy savings of about $0.05 per square foot were experienced by the VAV system economizer over the non-economizer VAV system in cold and temperate climates. The economizer on the CV system was much less advantageous due to increases in heating energy costs for this particular system, and was actually more expensive under some utility rate structures.

- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B
- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: VAV with constant outdoor air control and an economizer was overall the best, while VAV with constant outdoor air fraction (fixed outdoor damper) and no economizer was overall the worst system among those studied**

Explanation: Of all the ventilation systems and controls studied, the VAV system with constant outdoor air flow (variable outdoor air fraction), which in cold and temperate climates is combined with an economizer and proper freeze control and humidity control, provided the best overall performance considering outdoor air flow, thermal comfort and energy efficiency. The VAV system with a fixed outdoor air fraction (fixed damper) and no economizer provided the worst overall performance because it failed to deliver adequate outdoor air most of the time and had no energy benefit.

- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B
- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

What Kind of Energy Penalty was Associated with Raising Outdoor Air from 5 cfm to 20 cfm per Person? (Large Office Building)

- **Key Result: Raising outdoor air to meet ASHRAE Standard 62-1999 in most of the office buildings modeled resulted in very modest increases in energy costs**

Explanation: The main factor affecting the energy cost of raising outdoor air flow was occupant density, such that buildings with higher occupant density experienced higher energy cost increases. But for office buildings with 7 persons per thousand square feet, with moderate chiller and boiler efficiencies, and operating in daytime mode for 12 hours per work day, raising outdoor air flow from 5-20 cfm (2 - 9 L/s) per occupant raised HVAC energy costs by 2% - 10% (total energy costs by 1%-4%) depending upon system and climate variations. This is generally less than is commonly perceived and suggests that the issue needs a more careful examination by practitioners. The cooling cost increases in the summer months were counterbalanced by cooling cost savings during cooler weather. Cost increases were higher for economizer systems than systems without economizers because much of the cost savings from higher outdoor air flow rates during cooler weather was already captured by the economizer system. For buildings with occupant densities of 3 persons per thousand square feet, energy costs increases were less. By contrast, office buildings modeled with 15 persons per 1000 square feet experienced up to 21% increase in HVAC energy (or up to 8% increase in the total energy bill).

- Energy Impacts of Increasing Outdoor Air Flow Rates from 5 to 20 cfm per Occupant in Large Office Buildings - (PDF 22 pp, 94KB) EPA Document number EPA-4-2-S-01-001D

What Energy Penalty and Other Problems were Experienced when Outdoor Air was Increased in Schools and Auditoriums?

- **Key Result: VAV systems in education and auditorium required special adjustments for meeting the high outdoor air flow rates of ASHRAE 62-1999**

Explanation: In the education and auditorium buildings, the higher per occupant outdoor air requirements sometimes exceeded the total supply air needed to control thermal comfort. Even with the constant outdoor air damper control on the VAV system, the VAV box minimum settings had to be raised to what appear to be uncommonly high levels (e.g., 50% - 100% of peak flow), in order to maintain 15 cfm per occupant during part load.

- Potential Problems in IAQ and Energy Performance of HVAC Systems

When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings - (PDF 41 pp, 140KB) EPA Document number EPA-4-2-S-01-001F

- **Key Result: Controlling humidity can be a problem for education buildings, auditoriums or other buildings with very high occupant densities where HVAC systems must deliver high outdoor air flow to meet ASHRAE Standard 62-1999**

Explanation: Relative humidity frequently exceeded 60% and occasionally exceeded 70% in all climates in the education buildings and the auditoriums even though the cooling coils were adequately sized to handle peak loads and the indoor temperatures were well controlled. Problems occurred at part load during mild weather when the outdoor relative humidity was high. The increased dominance of the outdoor air at 15 cfm per occupant meant that the heating and cooling system had to deal with wide ranges in the sensible to latent heat ratio, so that humidity as well as temperature had to be part of the control regime. Controlling humidity may be a subject of special concern in buildings with very high occupant densities which meet the outdoor air flow requirements of ASHRAE Standard 62-1999.

  - Potential Problems in IAQ and Energy Performance of HVAC Systems When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings - (PDF 41 pp, 140KB) EPA Document number EPA-4-2-S-01-001F

- **Key Result: The outdoor air requirements of ASHRAE Standard 62-1999 for education buildings, auditoriums and other buildings with very high occupant densities can create a significant energy burden**

Explanation: When outdoor air ventilation rates were raised from 5 to 15 cfm per occupant in the education building and the auditorium, HVAC energy costs for the school rose by 15% - 32% (5% - 14% of total energy cost), and by 26% - 67% (9% - 25% of total energy cost) in the auditorium. These results include all adjustments to insure adequate outdoor air flow at part load, and the control of relative humidity to 60% or below.

  - Potential Problems in IAQ and Energy Performance of HVAC Systems When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings - (PDF 41 pp, 140KB) EPA Document number EPA-4-2-S-01-001F

How Were Peak Loads and Downsizing Potential Affected by Raising Outdoor Air Flow Rates? (All Buildings)

- **Key Result: Peak loads, and therefore equipment capacity requirements, may be significantly impacted when outdoor air ventilation rates are raised**

Explanation: Raising the rate from 5 to 20 cfm per occupant in office buildings often raised peak coil requirements by 15% - 25%, and created preheat requirements where none had previously existed. Raising the outdoor air flow rate from 5 to 15 cfm increased peak loads by 25%-35% in the education building, and by 35% - 40% in the auditorium. This could provide real limits to downsizing strategies which are often part of an energy efficiency strategy, and calls for specific steps to reduce peak loads without sacrificing outdoor air requirements. It also suggests that indoor air consultants advising clients of existing buildings to raise outdoor air flow rates in order to reduce indoor air quality complaints, should first consider the potential need to either increase capacity or reduce peak loads. Buildings without sufficient capacity may find themselves unable to maintain thermal comfort in the face of these higher outdoor ventilation rates, or in the worst scenario, may experience coil damage.

- Peak Load Impacts of Increasing Outdoor Air Flow Rates from 5 to 20 cfm per Occupant in Large Office Buildings - (PDF 17 pp, 74KB) EPA Document number EPA-4-2-S-01-001E

Can Energy Recovery Systems Solve the Energy and Humidity Problems of Higher Outdoor Air Flow in Schools and Auditoriums?

- **Key Result: Energy recovery technologies may potentially reduce or eliminate the humidity control, energy cost and sizing problems associated with ASHRAE Standard 62-1999 in education buildings, auditoriums, and other buildings with very high occupant density**

Explanation: Available literature and other modeling studies suggest that both latent and sensible energy recovery systems may significantly reduce or eliminate the associated problems of controlling thermal comfort, reducing energy costs, and downsizing equipment needs while meeting the outdoor air requirements of ASHRAE Standard 62-1999 in high occupant density buildings. Corroborating research could be of great value. Cost issues would include the capital cost of the energy recovery equipment, capital cost savings from downsizing, and the annual energy savings from the energy recovery system.

- The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings - (PDF 20 pp, 80KB) EPA Document number EPA-4-2-S-01-001G
- Software tools to assess the potential for humidity control, outdoor air control, and economic viability of energy recovery systems in schools are available, see www.epa.gov/iaq/schooldesign/saves.html

Was Protecting IAQ a Hindrance to Achieving Energy Reductions During Energy Efficiency Projects?
(Office, School)

- **Key Result: Protecting or improving indoor air environmental quality during energy efficiency retrofit projects need no hamper energy reduction goals**

Explanation: Many energy efficiency measures with the potential to degrade indoor environmental quality appear to require only minor adjustments to protect the indoor environment. When energy efficiency retrofit measures (including lighting upgrades), which were adjusted to either enhance or not degrade indoor environmental quality, were combined with measures to meet the outdoor air requirements of ASHRAE Standard 62-1999, total energy costs were cut by 42% - 43% in the office building and by 22% - 37% in the education building . The IAQ measures included raising outdoor air flow from 5 to 20 cfm per occupant in the office building and from 5 cfm to 15 cfm in the education building, installing a constant outdoor air flow control, and controlling humidity to 60% maximum. When measured against the base building energy costs, these IAQ measures meant that only 2%-3% of energy savings in the office building, and 3% - 9% in the education building were foregone. However, an energy recovery ventilation system would be expected to significantly reduce or eliminate these penalties in the education building. There appears to be demonstrable compatibility between indoor environmental goals and energy efficiency goals, when energy saving measures and retrofits are applied wisely.

- The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings - (PDF 20 pp, 80KB) EPA Document number EPA-4-2-S-01-001G

- **Key Result: Operational measures that are compatible with IAQ save far more energy than operational measures that are incompatible with IAQ**

Explanation: Operational measures compatible with indoor environmental quality are expected to cut total energy costs by 10%-15% or more. These principally include preventive maintenance and tune-up of the HVAC, and reducing lighting use during unoccupied hours. By contrast, avoiding operational measures that degrade indoor environmental quality such as wider temperature control bands and reduction in operating hours meant that total energy reductions of only 3%-5% in the office building, and 7%-10% in the education building were foregone. It may make little sense to pursue energy reduction activities that compromise IAQ and run the risk and potential liability of IAQ related illnesses and complaints, when the energy saving potential for compatible measures is so much greater in comparison.

- The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings - (PDF 20 pp, 80KB) EPA Document number EPA-4-2-S-01-001G

Energy Retrofit Measures and IAQ

Retrofit Measures Compatible with IAQ

Most energy retrofit measures are generally compatible with IAQ provided that they are instituted with certain IAQ protections.. Staged energy retrofits that include provisions to protect IAQ and that provide additional outdoor air to meet the ventilation requirements of ASHRAE Standard 62-1999 can result in substantial energy saving. Some compatible measures and the steps needed to protect IAQ are discussed below.

Improving Energy Efficiency of the Building Shell

Tightening the building shell will reduce infiltration. Therefore, mechanically supplied outdoor air may need to be increased to insure applicable ventilation standards are met, and that there is sufficient make up air to satisfy exhaust ventilation requirements.

Reducing Internal Loads Such as Lighting and Office Equipment Upgrades

Reduced internal loads will reduce supply air requirements in VAV systems. Therefore, the outdoor air flow may need to be increased to meet applicable ventilation standards. Lighting must be sufficient for general lighting and task lighting needs.

Upgrading Fans, Motors, and Drives

All upgrades are compatible with IAQ and need no special IAQ protections.

Upgrading Chillers and Boilers

All upgrades are compatible with IAQ. Installation must be done so as to provide good access for cleaning and maintenance. Sufficient air must be supplied to boilers to support combustion and the proper exhaust of flue gasses. The boiler room should be under positive pressure. A dedicated outdoor air supply to support combustion is desirable if possible.

Energy Recovery Ventilation (ERV) Systems

Energy recovery ventilation systems provide excellent opportunities for saving energy, controlling humidity, and providing sufficient outside air to promote IAQ in high occupant density buildings. ERV systems also increase the potential for downsizing other HVAC components. EPA's software for assessing the IAQ and energy and economic potential of ERV systems for schools is available to interested parties.

Equipment Downsizing

Prudent avoidance of over-sizing equipment reduces first costs and energy costs. However, capacity must be sufficient for thermal and outdoor air requirements during peak loads in both summer and winter.

Latent load should not be ignored when sizing equipment in any climate. Inadequate humidity control has resulted in thermal discomfort and mold contamination so great as to render some buildings uninhabitable.

Energy recovery systems may enable chillers and boilers to be further downsized by reducing the thermal loads from outdoor air ventilation.

Retrofit Measures That Are Incompatible With IAQ

Most retrofit measures are compatible with IAQ provided that the precautions identified above are adhered to. Perhaps the most critical issue is downsizing. Often, equipment is downsized, without considering the ventilation requirements of ASHRAE 62-1999. In such cases, if IAQ problems occur because of inadequate ventilation, the system would be incapable of solving the problem.

Operational Measures for Energy and IAQ

Operational Measures That Are Compatible With IAQ

Most energy conservation measures are compatible with IAQ or can be made compatible as long as actions are taken to protect against potentially adverse IAQ effects. This section delineates measures that are compatible and, where they occur, identifies the potentially adverse effects to be avoided.

Preventive Maintenance (PM) of HVAC

Preventive maintenance will improve IAQ and reduce energy use by removing contaminant sources (e.g. clean coils/drain pans), and insuring proper calibration and efficient operation of mechanical components (e.g. fans, motors, thermostats, and controls). Data from many buildings throughout the United States show that a properly commissioned building with controls and equipment functioning properly can save 5%-15% in total building energy cost.

Air-Side Economizer

Economizers use outdoor air to provide free cooling. Economizers potentially improve IAQ when economizer is operating by helping to insure that the outdoor air ventilation rate meets IAQ requirements.

Economizers are not practical or advisable in hot-humid climates. Except in dry climates, moisture control must be incorporated. For example:

- On/off set points could be calibrated to both the temperature and moisture conditions of outdoor air to avoid indoor humidity problems.
- Outdoor air may be dried using desiccants prior to entering the indoor space.
- Economizer may shut down when a preset outdoor air temperature is exceeded.

Economizer may need to be disengaged during significant outdoor air pollution episodes if that is a problem, or an air cleaning capability could be applied to the outdoor air prior to entering the occupied space. Economizers may be expected to reduce annual HVAC energy costs in cold or temperate climates.

Night Pre-Cooling

Cool outdoor air at night may be used to pre-cool the building while simultaneously exhausting accumulated pollutants. This is called building flush. However, the cool outdoor air may also have a high moisture content and could humidify the building at night, so caution is suggested. In addition to preventing microbiological growth, controls should stop pre-cooling operations if the dew point of the outdoor air is high enough to cause condensation on equipment.

Reducing Demand Charges

Night pre-cooling and sequential startup of equipment to eliminate demand spikes are examples of strategies that are compatible with IAQ. Load shedding strategies, which are potentially incompatible with IAQ, may involve changing the space temperature set points, or reducing outdoor air ventilation during occupancy. These can create IAQ problems and complaints.

Supply Air Temperature Reset

Supply air temperature may sometimes be increased to reduce chiller energy use in VAV systems. However, fan energy will increase because more air is required to provide the same cooling. Higher (lower) supply air temperatures in a VAV system will increase (decrease) supply airflow - this may increase (decrease) outdoor airflow in systems that provide a constant percentage of outdoor air. A higher supply air temperature also reduces dehumidification potential and could create excess indoor humidity.

CO_2 Controlled Ventilation

CO_2 controlled ventilation varies the outdoor air supply in response to CO_2 which is used as an indicator of occupancy. CO_2 controls may be useful for reducing energy use for general meeting rooms, studios, theaters, educational facilities, etc., where occupancy is highly variable, and irregular.

A typical system will increase outdoor air when CO_2 levels rise to 600-800 PPM to insure that maximum levels do not exceed 1,000 PPM. The system should incorporate a minimum outside air setting to dilute building related contaminants during low occupancy periods. CO_2 sensors must be calibrated periodically and set points may need to be adjusted based on outdoor CO_2 levels around the building.

Reduce Light Usage During Unoccupied Hours

Reducing light usage during unoccupied hours saves considerable energy, is easy to administer, and is compatible with IAQ.

IAQ Incompatible Operational Measures

Attempts in the past to save energy have needlessly compromised IAQ and resulted in occupant complaints and/or serious illness. This section delineates those measures to avoid, and demonstrates that the potential energy loss from avoiding these measures is not significant.

Reducing Outdoor Air Ventilation below Standards

Applicable ventilation standards usually specify a minimum continuous outdoor airflow rate per occupant, and/or per square foot, during occupied hours. Standards are designed to insure that pollutants in the occupied space are sufficiently diluted with outdoor air. Reducing outdoor airflow below applicable standards can degrade IAQ and has low energy saving potential relative to other energy saving options.

Reducing HVAC Operating Hours

Delayed start-up or premature shutdown of the HVAC can evoke IAQ problems and occupant complaints. The loss in energy savings from avoiding this strategy is not significant in a well-run building.

- An insufficient lead-time prior to occupancy can result in thermal discomfort and pollutant-related health problems. IAQ problems can last for several hours, as the HVAC system must overcome the loads from both the nightly setbacks and from current occupancy. This is a particular problem when equipment is downsized.
- Shutting equipment down prior to occupants leaving may sometimes be

acceptable provided that fans are kept operating to insure adequate ventilation.

Relaxing Temperature / Humidity Set Points Below Standards

Occupant satisfaction and productivity is highly sensitive to temperature and humidity conditions. In addition, even a slight thermal discomfort can exacerbate pollution-related problems when they occur compounding the complexity and cost of diagnosis and remediation. The loss in energy savings from avoiding this strategy is not significant in a well-run building.

International Performance Measurement and Verification Protocol (IPMVP)

This document discusses procedures to quantify energy conservation measure (ECM) performance and energy savings in buildings. An appendix covering indoor environmental issues has also been developed. Download a PDF version of the December 1997 protocols (DOE/EE-0157) (PDF, 192 pp, 647KB)

Calculating Energy Saving Potential of Upgrades

EPA's Energy Star Program encourages building owners and managers to upgrade their equipment to save energy. A number of technical assistance packages are available to Energy Star Partners and to others on the WEB. Browse through the Energy Star website to take advantage of this assistance.

IAQ Building Education and Assessment Model (I-BEAM)

I-BEAM Text Modules

- Fundamentals of IAQ in Buildings
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- I-BEAM Forms

Diagnosing and Solving Problems
(PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

Text Modules: Diagnosing and Solving Problems

Contents

- **Contrasting Diagnostics in Industrial and Commercial Facilities**
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Contrasting Diagnostics in Industrial and Commercial Facilities

In industrial environments, worker exposure to specific known sources of industrial contamination must be controlled. The diagnostic process is characterized by measurements of the target contaminants and comparisons of the concentrations to occupational standards of acceptable exposure developed specifically to protect industrial workers.

Occupational standards of acceptable exposure for industrial workers are available. They are designed to protect workers from levels that would cause "material damage of health and functional capacity" and where controls are technically and economically feasible in industry. Two commonly used standards are the:

- Permissible Exposure Limits (PELs) established by the Occupational Safety and Health Administration (OSHA).
- Threshold Limit Values (TLVs) established by the American Conference of Industrial Hygienists (ACGIH).

Use of occupational standards are NOT appropriate for use in commercial facilities.

Commercial environments are characterized by hundreds of sources producing multiple contaminants at much lower than industrial levels. Indeed, exceeding occupational standards in a non-industrial environment would indicate very serious indoor air quality concerns. In commercial environments, indoor air quality depends on how these sources and contaminants interact with air flow patterns, heat and humidity factors, and occupant patterns in time and space within the building. Looking for patterns and relationships in source emissions, occupancy, activities, ventilation and direction of airflow is most productive in these cases.

Measurements are designed to characterize the amount of outdoor air that is delivered to occupants, comfort indicators, the performance of the HVAC system, pressure relationships, and air flow patterns that could transport contaminants from potential sources to the occupied areas of the building. Measurements of specific contaminants are very seldom warranted.

General Diagnostic Process for Commercial Facilities

Generally, there are three steps in a diagnostic process.

1. Determine if this is an emergency. If it is, take actions immediately to protect occupants and property. Determine is the problem is building related and, if it is, continue with steps 2 and 3.
2. Proceed through a deliberate process of characterizing problem finding clues as to causes, and communicating with occupants and operators.
3. Check specific causes until the problem is solved.

Identifying an Emergency

Emergencies are situations in which a limited time is available to avert or deal with serious health problems or property damage. Examples include:

- Hazardous material spills
- Flooding on porous materials
- Gray water (e.g., sewer) spills
- Gas leak
- Sudden onset of headaches, dizziness, drowsiness, nausea, and/or combustion odors (could be carbon monoxide poisoning)
- Widespread breathing difficulties, chest tightness, or respiratory irritation (potential serious infectious or allergenic agent)
- Diagnosed Legionnaires disease or tuberculosis

Taking Action in an Emergency

The object of initial action in emergency situations is to deal with the situation creating the hazardous conditions first, including getting people out of harm's way.

- Immediately notify and seek assistance from an appropriate authority (e.g. health department, hazardous waste office, fire department, gas utility etc.)
- Evacuate the area if needed
- Obtain medical assistance
- Ventilate affected areas with large quantities of outdoor air using temporary fans if necessary
- Inform building occupants of problem, what is being done, and maintain clear communications
- Begin remediation procedures

Characterizing Problems

Purpose

The processes in this phase are designed to diagnose and solve typical indoor air quality problems that are not emergencies. The information provided is designed to help the user develop a *diagnostic way of thinking* about indoor air quality problems. IBEAM also provides a set of forms to aid in diagnosing and solving problems.

Iterative Diagnostic Process

An IAQ investigation is like detective work - defining the problem, looking for clues, and finding a solution through an iterative process of narrowing the possible causes, and developing and testing hypotheses. (see Flow Chart for example).

Clues may be found in basic information about the problem. Seeking the right information from occupants, examining building components with an educated eye, and making some simple diagnostic measurements can probably solve most problems. Determine:

- What are the symptoms? What are the symptoms or substance of the complaint? Answers can give clues as to potential type of cause(s) (e.g. type of contamination, inadequate outdoor air, temperature/humidity issue, etc.).
- Where is the problem? Local or widespread, in one HVAC zone or more, on one side of the building or all sides, one floor/room or throughout the building? Answers can give clues as to the nature of the cause(s) such as a local source or local HVAC component problem, or a source that is widespread throughout the building, a central HVAC problem, a problem common to all air handlers or just one.
- When does it occur? Times, time pattern, time in relation to individual activities, time in relationship to other activities in the building, time in relation to occupancy in building? Answers can give clues as to whether it is related to the building or elsewhere, and what activities may be associated with the cause(s), whether the cause(s) are occupant related or building related.
- Who is the problem experienced by? An individual or several, just in person(s) with preexisting sensitivities or across the board? Answers provide clues as to whether or not the individual(s) may have special needs that, if accommodated, could solve the problem.

Use I-Beam's Occupant Complaint Record forms to help collect this information.

What are the Symptoms?

Some symptoms or conditions suggest that certain causes are more likely than others are. Is the cause of the problem most likely to be a chemical source, a biological source, a lack of outdoor air, a thermal comfort problem, or not related to the building? In conjunction with the other information you obtain, use the table below to help narrow your first line of investigation. If the primary choice is not fruitful, go to the secondary choices.

	Potential Cause		
Symptom/Condition	**Primary**	**Secondary**	**Comment**
Cough, congestion, chest tightness, shortness of breath, fever, chills	Biological	Chemical/particle	• Check for microbial contamination in room/area, in the ductwork, in the cooling tower, or at the air handler • Check for mold
Diagnosed infection or allergic disease	Biological	*(none)*	• Obtain information about causes from diagnosis • Check for microbial contamination in room/area, in the ductwork, in the cooling tower, or at the air handler • Check for mold
Swelling, itching, skin rash	• Biological (allergen) if small numbers involved • Chemical/particle if large numbers involved	• Chemical/particle if small numbers involved • Biological if large numbers involved	• Check for microbial contamination in room/area, in the ductwork, in the cooling tower, or at the air handler • Check for mold • Check for fiberglass contamination from insulation in ducts or around building envelope • Check for renovation/remodeling sources • Check for painting, adhesives, solvents, petroleum products in maintenance or housekeeping • Check for aerosol products, cleansers, waxes in housekeeping • Check major occupant sources such as printing, dry cleaning, hair salons etc.
	Potential Cause		
Symptom/Condition	**Primary**	**Secondary**	**Comment**
Sinus headache	Biological (allergen), e.g. pollen, mold	Chemical particle	• Could be allergen outside or inside. If outside, consider increasing filtration efficiency

Wheezing, asthma	Asthma triggers • dust mites • animal dander • pests • tobacco smoke • mold • ozone	*(none)*	For dust mites • Check dust mites Keep relative humidity below 50% • For animal dander • clean all surfaces • clean carpets and upholstered furniture For cockroach or rodent allergens: • institute or check integrated pest management procedures For tobacco smoke • ban smoking, or • check adequate operation of smoking lounge For mold • check for mold For ozone • Check information about outdoor ozone levels • Consider cleaning outdoor air brought into building • Check electrostatic precipitators or other electronic air cleaners which can produce ozone • Check for indoor ozone generating air cleaner See other responses associated with biological pollutants

	Potential Cause		
Symptom / Condition	**Primary**	**Secondary**	**Comment**
• Mild discomfort in eyes, nose, or throat • Mild headaches • General lethargy • Generally not feeling well	• Lack of outdoor air • Temperature or humidity	• Chemical/particle • Biological	• Check outdoor air • Check thermostats • Monitor temperature, and relative humidity • Check for mold
Stuffy air	• Lack of outdoor air • Temperature too high and/or relative humidity too high	Insufficient air movement	• Check outdoor air • Check thermostats • Monitor temperature and relative humidity • Check volume of supply air
Too hot	• Temperature and/or relative humidity too high • Humidity too high • Lack of outdoor air	Insufficient air movement	• Check thermostats • Monitor temperature and relative humidity • Local heat source/high radiant temperature • Check volume of supply air
Dry air	• Temperature too high • Humidity too low • Particle pollutants	Lack of outdoor air	• Check thermostats • Monitor for temperature and relative humidity • Check for dust or other particle sources Check housekeeping. • Check over ventilation in heating season • Too much infiltration/exfiltration • Check outdoor air
Odors			
• Musty • Stale air/body odor • Dirty socks • Sewer • Petroleum • Chemical (metallic taste) • Gas fumes • Pungent odor	• Mold • Lack of outdoor air/air mixing • Dirty coils/filters, lack of outside air • Sewer gas, drain traps, sanitary vents	• Leaky tanks, spills • Cleaning products, pesticides, preservatives • Combustion spillage • Particles burnt on a hot surface	• Check for mold • Check outdoor air • Check coils/filters; Check for mold in air handler • Check sewer gases, sewer line leak, soil air drawn from leach field, septic tank • Check fuel tanks for leaks • Check recent use of chemical products • Check combustion spillage • Check for particles burning on heat exchangers or hot baseboard heaters/radiators

Where Symptoms Occur

Are symptoms local to a given room, floor, air handling zone, side of the building, or are they widespread or scattered throughout the building? The possibilities are numerous. The examples below will help guide the user into the kind of investigative thought process (detective work) that can help find the cause(s) of the problem.

Symptoms	Potential Source Examples	Potential HVAC Problem Examples	Potential Pathway Examples

Local	• Individual smoking
	• Smoking lounge
	• Kitchenette
	• Printers/copiers
	• Mold/moisture
	• Storage area
	• Local remodeling
	• Furniture
	• Outdoor sources near air intake of
		• Local exhaust
		• Local diffuser
		• Local thermostat
		• Local air supply
		• Contaminated local duct
		• VAV box malfunction
		• Problem in single zone HVAC system
		  ◦ contaminated
		  ◦ filter
			• Local HVAC duct
			• Source on lower floor/basement traveling up nearby stairwell/elevator
			• Source elsewhere in the building coming through local penetration in wall/floor
			• Room air
			• Hallway

	single zone air handler or local window/door • Overcrowding in zone • Significant heat sources (cooling loads) in zone • Outdoor source entering outdoor air vent in single zone air handler • Lack of housekeeping in the area	• maintenance activity in • lack of outdoor air, etc.	

Interior zone	• Source located in interior zone
	  ◦ Copy room
	  ◦ Mechanical room
	  ◦ Storage closet, etc.
		• Interior zone getting less supply air and outdoor air than exterior zones because thermal loads are less	*(none)*

Widespread	• Widespread modeling/renovations • Building fabric/furnishings • General housekeeping • General building maintenance • General overcrowding • Significant heat sources (cooling loads) beyond central system capacity • Outdoor source reaching all outdoor air intake vents, or vent of central air handler • lack of outdoor air	• Problems (see above) with a central HVAC system • Overall lack of HVAC maintenance • Maintenance activity performed on all air handlers	• Local source dispersed throughout building through central HVAC system

When Problems Occur

Looking for patterns in time, and then relating these patterns to various occupant or building activities, or to your knowledge of HVAC operations, can give clues as to the potential cause(s). The table below provides some examples of patterns and possible causes. It is designed to help the user understand how knowledge of the time pattern can help form a hypothesis of the cause. These are only examples.

Identifying Diagnostic Patterns

Pattern of Occurrence	Possible Causes
Mornings, (may be more severe on Monday morning), then dissipates as day/week progresses	• Failure to flush building at night and on weekends • Late start-up of HVAC or late outdoor air damper openings during startup • Morning traffic pollution entering outdoor air vent
Latter part of the week	• Occupants or their activities may be the source, suggests possible inadequate outdoor air in HVAC to dilute pollutants.
Recurrent on a particular schedule	• Recurrent occupant/tenant or building maintenance or housekeeping activity which takes place just prior to the symptoms • HVAC schedule/sequence related to symptom recurrence
Hot weather	• Emissions from recently installed furnishings. • Inadequate HVAC capacity • Economizer control malfunction
Mild temperatures	• Economizer controls malfunction • VAV system at part load delivering little supply air and little outdoor air
Cool weather	• Freeze stat control being tripped off
Does not go away when leave the building	• May not be building related

Who Experiences the Problem?

If it is just one individual, it may be that this individual is particularly sensitive to a contaminating agent in the building, or the problem may be local to their workspace. If all the individuals affected have a common preexisting condition such as a particular allergy, knowledge of their sensitivity may help find the cause(s) and may lead either to elimination of the causal agent or work arrangements that will minimize their exposure.

Checking Potential Causes

Having developed some hypotheses about potential causes from examining clues suggested by the "what," "where," "when," and "who" of the problem, do some simple checks to see if the problem is obvious. Examples below suggest some things to check in looking at common sources or causes.

Checking Potential Causes

Potential Cause	Things to Check
Mold	• A musty smell suggests the presence of mold. • Relative humidity should be below 60% at all times. • Check for visible mold, standing water, or moist material in the complaint area (carpet, walls, ceiling tile). • Check for evidence of condensation on windows or cold surfaces. • Check for lack of adequate housekeeping in the affected area? • Check pipe entries into the area that trace back to the basement or crawl space. • Check for signs of mold or standing water, or moist material in the air handler, ductwork, crawlspaces, or basements. • Drain pans should be clean and draining. • Filters should be clean and dry. If filters have not been changed in a long while because they are not sufficiently loaded, they may have developed mold. Try changing them anyway. • Check return ducts that pass through a crawlspace, basement, or moist area for any potential leaks. • Check for roof leaks, plumbing leaks, or ground drainage problems. *Excess moisture or humidity can foster mold/fungi, dust mites, and some bacteria.*
Particles	• Check if anyone is smoking in the area suggesting the need to ban or enforce smoking policy. • Make sure that the smoking lounge is properly isolated and ventilated. • Check for major indoor particle sources such as a printing shop indicating the need to control emissions. • Check for visible dust, especially in high or hard to access areas, indicating the need for improved housekeeping. • If vacuuming occurs during occupancy, try using high efficiency vacuum filtration or a change in vacuuming schedule to non-occupied hours. Periodically use deep extraction cleaning of carpets. • Check to see if outdoor air vents are near vehicle sources or other particle sources. • Check the filters and filtration system and consider increasing filter efficiency? • Use walk off mats in entryways to keep dirt out.

	Particles can themselves be harmful, and may contain chemicals that are harmful. Source control, good housekeeping, and filtration can be effective strategies
Housekeeping Sources	• Check schedules to see if complaints occur during or just after certain housekeeping activities. • Check to see if any new housekeeping products or methods were introduced just prior to symptom onset. • Check for changes in personnel applying housekeeping products or methods prior to onset of symptoms. • Check to insure that housekeeping products are used as directed • Check for proper storage of housekeeping products stored nearby. • Check to insure that housekeeping products are mixed properly, and at proper strength. *Housekeeping is important to good indoor air quality, but it also contains the potential for creating indoor air quality problems.*
Building Sources	• Check to see if there had been recent painting, roofing, remodeling or pesticide application just prior to the onset of symptoms. • Check for installation of new furniture or partitions just prior to onset of symptoms. • Make sure that outdoor air supply during startup occurs prior to occupancy. • Insure that outdoor air supply adequate during all operating modes. Check outdoor air operating mode just prior to and during symptom occurrence. • Insure that outdoor air flush of building contaminants occurs during unoccupied hours. *Source control for major building sources , protocols during remodeling and renovation, and adequate outdoor air strategies for general sources are important dimensions of controlling building source contamination.*
Outdoor sources	• Check for changes to surrounding land use that could pollute the outdoor air near the building. • Check for changes to building services, such as trash removal, loading dock, and parking areas, landscaping, or storage areas that could contaminate the outdoor air at the outdoor air intake. • Check pollen levels when symptoms occur. • Check construction activity nearby. *Important outdoor sources can be building related, traffic related, land use related or vegetation related. Source type, source location and wind direction are important considerations.*
Sewer gas or similar odor	• Check for signs of a sewer leak. • Check building sanitary vents in proximal relation to the outdoor air intake. • Insure there is water in all traps. • Check that the basement is not under negative pressure and is not drawing gas through sewer drains. • Check pathways (e.g. pipe chases, ducts) that could be delivering sewer gases into occupied areas. *Soil gases, including radon, can enter the building through the basement foundation, and odors from drain traps and sanitary vents should be controlled.*
Outdoor air supply	• Make sure that ventilation system is turned on, and that outdoor air grilles are not blocked. • Insure that air is coming out of the room air supply vent(s) in the complaint area, and that all controls, including pneumatic controls, are working properly. • Look for signs of short-circuiting in the complaint area. • Check that outdoor air dampers are operating properly. • Make sure that air is flowing into the outdoor air intake. • Check that time clocks are properly set (e.g. readjusted during daylight saving). • Make sure that economizer and freezer controls are functioning properly–turning on and off at the proper times. • Make sure that the supply and return fans are tracking properly. • Make sure that the VAV system provides a sufficiently high % of outdoor air during part load to insure adequate outdoor air under part load conditions. • Make sure system is balanced. *Outdoor air dilutes contaminants from all sources. The ventilation system should provide sufficient outdoor air to all occupied spaces during all operating modes.*
Air Handling Unit	*Also see Outdoor Air Supply.* • Make sure that the mechanical room is clean and free of any stored materials. • Insure that filters are clean and properly installed. • Make sure that drain pans are clean, properly sloped and draining. • Make sure that coils are clean. • Check for any leaks in mechanical equipment or ducts. • Make sure combustion flues are in good condition. • Make sure there is no backdraft from combustion flues under worst case conditions. *The air handler is at the heart of the ventilation system. All parts must be functioning well under all operating modes, clean, and protected from microbial growth.*
Local Exhaust	• Insure that exhaust is turned on when needed. • Insure that the exhaust fan is drawing air. • Insure that air is coming out of exhaust vents on the roof. • Insure that the source located so that the exhaust draws contaminants away from rather than toward occupants. • Make sure that the exhausted room is under negative pressure where make up air easily enters the room. *Local exhaust can be an effective means of controlling stationary local sources, but they must be properly located and operational .*

Basic Measurement Techniques

Most IAQ problems can be effectively diagnosed with educated observations, an awareness of odors, a sense of temperature and relative humidity, and a smoke pencil to observe the existence of and direction of air flows. It is often useful to also measure thermal comfort parameters using various instruments to measure temperature and relative humidity.

Occasionally, the diagnostician will want to measure airflow into, through, or out of ducts/vents, or calculate the percent of outdoor air in the supply air stream. Some diagnosticians may also find it useful to track carbon dioxide levels in occupied spaces over the course of the occupancy period, or compare carbon dioxide levels in the complaint area with levels in non-complaint areas.

The measurement techniques described here are simple and comparatively easy to perform. More complex measurement methods and those involving measurement of specific contaminants are usually not needed, and would normally require outside expertise. Diligently follow manufacturer's instructions on all measurement instructions.

Observing or Measuring Airflow

Using Smoke Tubes

Smoke tubes or smoke guns can provide a quick visualization of the path of the airstream and thus help identify pressure differentials. By dispensing a series of small “puffs” or "dribbles" the smoke can provide more information that a single large “cloud.” In occupied areas, if the smoke is dispersed in several seconds, this suggests good air circulation. Smoke tubes have a variety of uses and should be a staple of the building diagnostician. Use smoke tubes:

- Near supply air outlets - the dispersal pattern provides information about the velocity and direction of the supply air.
- Near exhaust vents to make sure the exhaust is drawing air out of the room.
- Near combustion chamber of combustion appliances to insure that there is no backdraft of flue gases.
  - Turn the appliance on.
  - Close all doors or other openings that might possibly be closed in normal operating conditions, and turn on all exhaust fans or other equipment (e.g., clothes dryer) that may exhaust air from the room.
  - Release puffs of smoke next to the combustion chamber and around the flue fittings (where flue gases might leak into the room) to detect any air movement from the flue or combustion chamber into the room.
  - If any flue gas leakage is occurring, turn off the appliance, open windows and doors, and exit the room. This is a potentially life threatening hazard.
- At drain trap openings make sure no air is flowing up from the trap.
- At duct seams to check for leakage.
- At the entrance to an exhausted room to insure the room is under negative pressure relative to the occupied spaces.
- At the entrance to a clean room to insure room is under positive pressure.

More generally, identify spaces that are positive or negative relative to other spaces to determine if this may be causing pollutants or moisture to travel in undesirable paths.

Measuring Outdoor Air Flow

The quantity of outdoor air supplied to a building can be ascertained using a flow hood or air velocity measurements. To check that outside air requirements are being met under all operating conditions, take measurements at minimum airflow.

- If an economizer is operating, turn the economizer off, or set the economizer shutoff temperature to the lowest setting.
- Since airflow varies during the day and over the seasons in VAV systems, VAV system controls should be made to operate at minimum flow conditions.

Measuring Air Flow with a Flow Hood (Preferred)

Flow hoods are designed to measure airflow through an opening (e.g., at supply air diffusers or return air grills, outdoor air intake) by placing the face of the flow hood over the opening and reading the computed airflow volume. The flow hood must completely cover the opening. If the opening is larger than the flow hood, the user can obtain a reasonable estimate by following manufacturer’s recommendations. Flow hoods will show the airflow in an easier, quicker, and more consistent manner than using a series of pitot tube or rotating-vane anemometer readings.

Measuring Air Flow with a Velocity Meter (Less Preferred)

Velocity meters (anemometer of pitot tube) are less expensive than flow hoods, but their accuracy is more problematic and they require greater attention to detail. An anemometer or Pitot tube can be used to measure the velocity of air passing over a point. To accurately represent the velocity through a duct or opening, multiple measurements must be taken. It is extremely important to follow measurement instructions supplied with the equipment to obtain an accurate reading. Airflow through the duct or opening is then measured by multiplying the area of the opening (e.g., square feet) by the average velocity of the air (e.g., feet per minute) to obtain airflow (cubic feet per minute).

Airflow = Free Open Area X Average Velocity

(ft3/m or m3/m) (ft2 or m2) (ft/min or m/min)

Calculating the Percent of Outdoor Air Using Carbon Dioxide (CO_2) Measurements (Not Preferred)

As a last resort, if outdoor air cannot be measured directly, one can measure the supply airflow and calculate the percentage of outdoor air using CO_2 measurements.

- Measure the total supply airflow using a flow hood or velocity meter.
- In quick succession, measure carbon dioxide in the supply air, the return air, and outdoor air (do not use calorimetric tubes for these measurements). An average of more than one measurement in each air stream is advisable to obtain accurate estimates.
- Calculate the percent outdoor air as follows:

$$\frac{\{CO_2\text{ (return)} - CO_2\text{ (supply)}\}\times 100}{\{CO_2\text{ (return)}-CO_2\text{ (outside)}\}} = \%\text{ outdoor air}$$

Outdoor air supply=(Supply airflow) X (% outdoor air)

Measurement of supply and return are best accomplished in an indoor space serviced by an AHU of interest. Outdoor air should be measured at the outdoor air intake of the AHU. Percent outdoor air is the same throughout the supply air stream of the AHU.

Note: It may be tempting to use temperature rather than CO_2 to measure percent outdoor air. This is not advisable because as the three airstreams approach each other, varying temperatures affect accuracy and the calculated result can deteriorate very significantly. For the same reason, the difference in CO_2 measurements in each air stream should be at least 200 PPM to insure an acceptable level of accuracy for this method.

Measurement of Thermal Comfort

Generally, independent measurements of temperature and relative humidity will be sufficient. However, some instruments will integrate these and other measurements and provide a read out of thermal comfort consistent with ASHRAE Standard 55-1992.

Temperature and Humidity

For temperature and humidity measurements, instruments can be a simple thermometer and humidity gauge, a sling psychrometer, or an electronic thermo hygrometer. Accuracy to within + or – 1^{o} F and + or – 5% RH is the objective of thermal comfort measurements. Readings should be made 3-6 feet off the floor, and at floor level. Persons suffering from cold feet may report that the room is "too cold."

Be sure that the meter is located away from direct sunlight or near a supply air outlet, or other heating/cooling sources. Refer to the manufacturer recommendations for the time needed to stabilize the reading, and maintain the frequency of calibration.

Acceptable Values

Direct reading instruments are readily available. Readings within acceptable ranges for thermal comfort.

Alternatively, a thermal comfort meter can be used. Such meters integrate several thermal comfort parameters and will provide a direct indication as to whether thermal comfort is in the acceptable range according to ASHRAE Standard 55-1992.

Measurement of Light

Measurements should be to ascertain that lighting conditions are adequate for the space. Use of a light meter to measure foot-candles (FC) should be conducted at the working surface in a horizontal plane 30 inches above the floor. Since the objective is to measure the task illuminant, daylight should be excluded. Thus, in an occupied area with windows, readings should be taken with the full use of interior shading (blinds or draperies) to reduce direct solar gain. When measurements are taken, the reflections from other strong light sources should be minimized. Light meters are generally sensitive to ambient temperatures, and should be only operated according the temperature range recommended by the manufacturer. Calibration is as important for light meters as it is for temperature and humidity measuring instruments.

Acceptable Values

Minimum foot-candle (FC) levels measured at the working surface:

- Ambient lighting for PC use: 20 FC
- Visual tasks of high contrast or large size office: 20 FC
- Visual tasks of medium contrast or small size: 50 FC
- Visual tasks of low contrast or very small size: 100 FC
- Hallways and stairwells measured at floor level: 5 FC
- Public spaces with dark surroundings (sidewalks, garages), measured at the floor: 2 FC

Measuring and Interpreting Carbon Dioxide (CO_2)

CO_2Measuring Instruments

Sorbent tubes are readily available for measuring CO_2 and they are inexpensive. However, with accuracy of only + 25%, sorbent tubes are not of much value for indoor air quality diagnostics. Though more expensive, instruments using infrared spectrometry with digital read-outs are more accurate and appropriate.

CO_2Value Indicators

The exhaled breath of occupants is the main source of carbon dioxide (CO2) in buildings. Because the concentration of CO_2 is highly correlated with levels of human bioeffluents (body odor), CO_2measurements are often used to indicate whether the outdoor air ventilation rate in the building is sufficient to handle the bioeffluents load.

ASHRAE ventilation standards of 15-20 cfm of outdoor air per occupant are designed to dilute human bioeffluents odor to an acceptable level. In general, 15 cfm per occupant will keep indoor minus outdoor CO_2levels below 700 PPM, while 20 cfm will keep indoor minus outdoor CO_2 levels below 500 PPM. (This corresponds to indoor values of 1000 PPM and 800 PPM when outdoor values are 300 PPM, which is assumed by ASHRAE.)

Interpreting CO_2 Measurements Above Threshold Values

Indoor CO_2 should be measured at peak values. Peaks usually occur around 11am and 3pm in a typical office environment. However, if measurements in the occupied space are <u>ever</u> above 1000 PPM:

- Check for improperly vented combustion appliances, which could also be producing carbon monoxide.
- Check the CO_2levels outside; and calculate the indoor-outdoor values and compare with the above mentioned thresholds for 15 and 20 cfm per occupant.

If neither of these conditions can explain why the CO_2 levels are above 1000 PPM, it is a valid presumption that the outdoor air ventilation rate is too low.

Interpreting CO_2 Below Threshold Values

If CO_2 levels are below the identified guidelines, this does not mean that the ventilation rate or that indoor air quality is satisfactory. CO_2 measurements below the designated threshold levels are <u>not</u> an indicator that either IAQ or outdoor air ventilation rates are satisfactory.

As a general measure of indoor air quality, CO_2 measurements do not account for non-occupant related contaminants, which can dominate the indoor environment. And as an indicator of the outdoor air ventilation rate, the use of CO_2 measurements will almost always tend to overestimate the true outdoor air ventilation rate, often by as much as 100% to 200%.

This is because the threshold values are based on the assumption that CO_2has risen to its theoretical steady state condition. As people occupy the building, when occupancy stabilizes, and when ventilation rates remain constant, CO_2 levels will rise and eventually reach steady state condition, and go no higher. The steady state value will be greater with higher occupant densities and lower outdoor air ventilation rates.

Unfortunately, it is extremely unlikely that steady state will have been reached.

- Under a typical outdoor air exchange rate of 0.5 air changes per hour, it would take 6 hours to achieve 95% of steady state conditions.
- But constant full occupancy in a building is seldom longer than 3 hours in the morning or 3 hours in the afternoon.
- Thus, measuring CO_2prior to steady state will always underestimate the true ventilation rate.

The extent of overestimation increases as occupant density decreases, and as the outdoor air ventilation rate decreases. In the majority of circumstances, CO_2 levels in occupied spaces will not achieve 1,000 PPM even when outdoor air ventilation rates are unacceptably low. The matter is further complicated by the fact that outdoor air ventilation rates are often not steady in VAV systems.

Observing Changes to CO_2 Values Over Time

Real-time measurements of $CO_2$with data-logging equipment can be also be used to see how CO_2 values rise and fall in an occupied space during the day, reflecting the pattern of changing occupancy, or changing outdoor air ventilation rates. This can provide clues as to what is happening in the building and this information can help in the diagnostic process.

Comparing CO_2 Values of Different Spaces in the Same Building

The investigator may wish to compare CO_2 values in the complaint area with values in other parts of the building. CO2 values in the complaint area higher than values in non-complaint areas suggest that outdoor air ventilation rates in the complaint area may be causing the problem.

Measuring Contaminants

Most often IAQ problems can be solved without measuring specific contaminants. Measurements are sometimes helpful:

- to test for clearly identified sources and clearly identified target contaminants
- to measure specific contaminants, such as radon, that have no acute affects but which could cause serious long term illness
- to test for mitigation effectiveness in controlling a source
- to compare with levels found in non-complaint buildings
- to insure the containment of a work area/construction area in an occupied building
- to document for liability or other legal or administrative reasons. When measurements are taken, qualified, experienced persons should take them and adhere to protocols and quality assurance procedures.

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: Renovation and New Construction

Important actions to protect and improve IAQ during each phase of the design and construction process are presented in this module.

Contents

- **Project Planning and Documentation**
  - Programming
  - Budgeting
  - Documentation Planning
  - Codes and Standards
  - IAQ-Related Documentation During Project Planning
- **Site Planning and Design**
  - Site Evaluation
  - Site Design
- **Building and HVAC Design**
  - Building Envelope
  - Space Planning
  - HVAC Design
    - General Design Provisions
    - Selected Design Provisions of ASHRAE 62-1999
  - HVAC Commissioning (Pre-Design and Design Phase)
    - HVAC Commissioning Planning
  - Exhaust of Indoor Sources and Pressure Control of Sources
  - General Air Circulation and Pressure Differentials
  - Filtration
  - Air Cleaning
- **Materials Evaluation and Selection**
  - Selecting Materials
  - Strategies for Selection and Installation of Materials

I-BEAM Text Modules

- Fundamentals of IAQ in Buildings
- Heating, Ventilation, and Air-conditioning (HVAC)
- IAQ Maintenance and Housekeeping Programs
- Indoor Air Quality and Energy Efficiency
- Diagnosing and Solving Problems
- **Renovation and New Construction**
- Managing for Indoor Air Quality
- IAQ Budgets and Accounts

- Overview of I-BEAM
- Overview of Text Modules
- Overview of Visual Reference Modules
- IAQ Budgets and Accounts
- I-BEAM Forms

Renovation and New Construction
(PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

- **Construction**
  - Monitoring the Construction/Renovation Process
  - Emission Control During Construction/Renovation
  - Isolation of Construction/Renovation Contaminants When Occupants are Present
- **After Construction**
  - Check the Building Envelope
  - Commissioning of HVAC System (Construction Phase)
- **Initial Occupancy After or During Construction / Renovation**
  - Protocol for Ventilation System Operation Under Initial Occupancy Conditions
  - HVAC Verification Under Occupancy Conditions
  - Indoor Air Quality Evaluation

Project Planning and Documentation

Programming

Establish IAQ design goals. For example, demonstrate that:

- Ventilation of outdoor air is consistent with ASHRAE Standard 62-1999 under all operating conditions.
- Comfort levels are acceptable to most occupants, and consistent with ASHRAE Standard 55, under all operating conditions.
- Significant expected sources of pollutant emissions are isolated from occupants using physical barriers, exhausts, and pressure controls.
- Outdoor air entering the building is protected from contamination from local outdoor sources and from building exhausts and sanitation vents.
- Full documentation of building and HVAC design with design intent for operation and maintenance.
- Provisions for easy access to HVAC equipment requiring periodic maintenance.
- Occupant exposure to construction contaminants is minimized using protocols material selection, preventive installation procedures, and special ventilation and pressure control isolation techniques.
- Building is thoroughly commissioned to insure that all IAQ design goals and related IAQ specifications are met.

Budgeting

Adequate budget to meet the IAQ design goals and specifications should be planned considering:

- Specialized services during each phase as may be needed: design, construction, initial occupancy.
- Time required for thorough commissioning and testing.
- Proper selection of the design team to include IAQ expertise.

Documentation Planning

As documentation accumulates, it should be organized and assembled in durable, moisture-resistant binders. Supplemented by operating and maintenance recommendations, project documentation creates a complete owner's manual for the building, and is good insurance against liability claims. Include:

- Documentation of project planning phase.
- Documentation of site and building design.
- Documentation of HVAC design.
- Documentation of construction and commissioning.
- Documentation of protection during initial occupancy.

Codes and Standards

Identify IAQ codes and standards to be met. For example:

- *ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality;*
- *ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy*
- *ASHRAE Guideline 1-1996, The HVAC Commissioning Process, can assist in establishing commissioning requirements.*
- *SMACNA Guidelines, 1995; IAQ Guidelines for Occupied Buildings Under Construction*

IAQ-Related Documentation during Project Planning

IAQ-related documentation during project planning would include:

- Building size and location.
- Types of occupants, noting special susceptibilities (e.g. young, elderly, people with asthma or other illnesses).
- Anticipated occupant densities (and potential for increased occupant densities), activities, and use patterns for each space.
- Major pollutant source activities.
- Uses requiring special environmental controls (e.g. computer rooms, libraries).

Site Planning and Design

Site Evaluation

Evaluate and document site conditions that can impact IAQ.

- General climate and site's microclimate, seasonal norms and extremes of temperature, relative humidity, wind speeds and directions.
- Local ambient air quality.
- Adjacent or nearby contaminant sources relative to building site and wind patterns.
- Potential future nearby sources (e.g. vacant nearby site zoned for industrial use).
- Outdoor noise sources.
- Soil and groundwater quality.
- Existing or potential underground contaminant sources (radon, underground fuel tanks, soil gas from landfill).
- Prior site history for potential soil or groundwater contamination (agricultural fertilizers and pesticides, landfill soil gases, toxic wastes from manufacturing plant).

Site Design

Plan the building location, orientation, and major site activities on the site to minimize contamination of the indoor environment. Relevant features should be documented, and noted on design drawings.

- Use setbacks as a means of separation from nearby pollutant sources. Since pollutants disperse quickly, a small increase in setback can mean a substantial decrease in pollutant concentration.
- Use landscaping as a buffer to offsite or onsite contaminants. Be careful not to place plants or soil close to air intakes where pollen, fertilizers or pesticides can

contaminate the air, or where overgrowth can block air entry. Consider full potential after plants have matured.
- Plan the shape and orientation of the building to allow prevailing winds to move contaminants away from the building. Avoid designs that would trap pollutants in stagnant air pockets.
- Provide for good water drainage and grading around the building foundation.
- Locate and design outdoor air intakes away from and upwind of pollutant sources.

Locate onsite pollutant sources away from and downwind of air intakes. Roadways, parking, loading areas, trash and chemical storage areas are typical sources.

Building and HVAC Design

Building Envelope

The building envelope will affect thermal comfort, HVAC capacity requirements, lighting quality (daylight) and view, potential infiltration of outdoor (or underground) contaminants, and moisture.

- Conduct thermal, moisture, and air migration analysis of envelope for maximum control.
- Use windows to provide daylight and views.
- Minimize radiant heat gains and losses through glass or uninsulated surfaces that will cause discomfort or unduly complicate HVAC design.
- Prefer thermally efficient building shells to increase thermal comfort and reduce HVAC loads and capacity requirements (reduce first costs).
- Avoid glare from windows or skylights.
- Use, and insure proper installation of, insulation to avoid cold spots with associated problems of condensation (mold) and thermal drafts.

Space Planning

Plan space uses to maximize the potential for isolating occupants from sources of contaminant through physical distance, physical barriers, exhaust systems, and pressure control.

- Identify all major sources of pollutants that may exist during occupancy.
- Plan spaces to isolate occupants from source contaminants.
- Provide for adequate exhaust; consider supplying loop of exhaust ductwork to facilitate later hookups.
- Develop pressure map to insure that contaminants from sources do not contaminate surrounding areas.
- Locate spaces with special environmental control needs where these needs can be efficiently accommodated.

HVAC Design

General Design Provisions

The HVAC system is critical to the building's ability to provide thermal comfort and ventilation of building contaminants. Outdoor air ventilation rate and indoor climate conditions should meet the design requirements (e.g., ASHRAE 62-1999 and ASHRAE 55-1992) under all operating conditions, including peak and minimum load.

Plan HVAC zones (with single thermostat) so that the thermal demands of all spaces within each zone are similar during all seasons. When different spaces having different thermal requirements are in the same zone, occupant discomfort is inevitable and solutions to complaints will be difficult (or impossible). Avoid placing thermostats in direct sunlight, near equipment or other heat sources, or on exterior walls.

Plan heating and cooling capacity to satisfy the peak (design) conditions that occur under extreme or worst-case conditions. Capacity requirements should be calculated considering both the sensible (heat) and latent (humidity) loads. Peak latent load may occur at subpeak sensible load. Capacity requirements should be calculated based on the outdoor airflow and thermal comfort requirements adopted in the design goals (e.g. ASHRAE 62-1999 and ASHRAE 55-1992).

Consider separate dehumidification prior to cooling, or energy recovery systems to improve performance and energy efficiency and reduce capacity requirements and therefore first costs. If humidification is needed, steam is preferred as a moisture source. The source of steam should be from potable water to avoid contamination from additives to boiler or steam water supplies.

Energy efficient building design, lighting, and HVAC design can reduce capacity requirements and lower first costs. (Energy Star)

Selected Design Provisions of ASHRAE 62-1999

ASHRAE Standard 62-1999 also identifies specific measures that should be taken to IAQ problems as they relate to the ventilation system. These measures are included elsewhere in I-BEAM, but it is useful to know that they are part of the ASHRAE Standard

Table 6.1 Selected Provisions of ASHRAE Standard 62-1999

Section No.	Standard
5.5	**Protect make-up air from sources:** Make-up air inlets and exhaust air outlets shall be located to avoid contamination of the makeup air. Contaminants from sources such as cooling towers, sanitary vents, vehicular exhaust from parking garages, loading docks, street traffic should be avoided. This is a special problem in buildings where the stack effect draws contaminants from these areas into the occupied spaces.
5.5	**Soil gases:** Ventilation practices that place crawlspaces, basements, or underground duct work below atmospheric pressure will tend to increase radon concentrations and should be avoided. (1)
5.6	**Microbial contamination of ducts:** Ventilating ducts and plenums shall be constructed and maintained to minimize the opportunity for growth and dissemination of microorganisms through the ventilation system.
5.7	**Stationary indoor sources:** collection and removal shall control contaminants from stationary local sources within the space exhaust as close to the source as practicable.
5.8	**Fuel-burning appliances:** Fuel-burning appliances, including fireplaces located indoors, shall be provided with sufficient air for combustion and adequate removal of combustion gases. The operation of clothes dryers and exhaust fans may require introduction of additional makeup air to avoid interference with fuel-

	burning appliances.
5.8	**Exhaust outlet:** Combustion system, kitchen, bathroom, and clothes dryer vents shall not be exhausted into attics, crawlspaces, or basements
5.11	**Relative humidity to control microorganisms:** Relative humidity in habitable spaces preferably should be maintained between 30% and 60% to minimize growth of allergenic or pathogenic organisms.
5.12	**Microbial contamination in HVAC equipment:** air handling unit condensate pans shall be designed for self-drainage to preclude the buildup of microbial slime. Provisions shall be made for periodic in-situ cleaning of cooling coils and condensate pans.
5.12	**Humidifier controls:** Steam is preferred as a moisture source for humidifiers, but care should be exercised to avoid contamination from boiler water or steam supply additives. If cold water humidifiers are specified, the water should originate from a potable source. Care should be taken to avoid particulate contamination due to evaporation of spray water.
6	**Contaminants:** Indoor air should not contain contaminants that exceed concentrations known to impair health or cause discomfort to occupants.
6.1.3.1	**Exhausted sources:** Rooms provided with exhaust air systems, such as kitchens, baths, toilet rooms, and smoking lounges, may utilize air supplied through adjacent habitable spaces to compensate for the exhausted air.
6.1, Table 2	**Office equipment:** Some office equipment may require local exhaust.
Forward	**Operation of the building:** Conditions specified in the Standard must be achieved during operation of buildings as well as in the design.
5.12	**Preventive Maintenance:** Air handling and fan coil units shall be easily accessible for inspection and preventive maintenance.
(1) This is true of any soil gas, such as sewer gases, or VOCs from underground storage tanks, contaminants for solid waste dumps, etc.	

HVAC Commissioning (Pre-Design and Design Phase)

See ASHRAE Guideline 1-1996, *The HVAC Commissioning Process* for detailed recommendations.

- Commissioning is a process to insure comprehensive planning, thorough documentation, and systematic implementation of plans.
- Commissioning begins in the pre-design phase, lasts throughout the construction process and into initial occupancy of the building.
- Systems may need to be re-commissioned periodically over the life of the building, particularly when changes in occupancy or equipment occur.
- Commissioning itself is an expense, but since it eliminates many problems, which add to construction costs, it need not add cost to the total construction budget. For example, commissioning the San Francisco Public Library was funded out of monies originally budgeted for contingencies.
- Commissioning can significantly increase energy efficiency and improve the indoor air quality of the final building.

HVAC Commissioning Planning

- Establish HVAC design criteria.
- Document HVAC design criteria and systems description.

- Prepare commissioning plan.
- Establish verification procedures.
- Document requirements for commissioning process:

Reports and submittals

- Drawings and schematics
- Checklists
- Operating and maintenance data
- As-built documentation

Exhaust of Indoor Sources and Pressure Control of Sources (Also see Section in HVAC Chapter)

Where major indoor sources are expected, exhaust ventilation and proper pressure control should be planned. Systems with direct exhaust from sources that also generate heat (e.g. copy machines) may also reduce HVAC energy requirements.

- Provide adequate exhaust for all localized sources of contamination.
- Plan for proper airflow and pressure control around sources.
- Seal return air plenum from exhaust air.
- Plan adequate source of make-up air (may be transferred from surrounding spaces).
- Insure room is under negative pressure relative to surrounding spaces and return air plenum.
- Smoking rooms should have 60 cfm of exhaust per person calculated at maximum capacity.

General Air Circulation and Pressure Differentials

The patterns of air circulation and flow, between outdoors and indoors, from basements and crawl spaces, between floors, and between spaces on each floor may be more important to IAQ than the HVAC system or system components. Air circulation patterns showing areas of positive and negative pressure should be drawn for the building as a whole, and for all occupied spaces and major source areas.

The flow of outdoor air into the building must be planned to slightly exceed the total airflow out of the building from all exhausts, combustion flues, and stack effect exfiltration to insure that the building is positively pressurized, to avoid infiltration of outdoor pollutants. (In cold climates the risk of condensation in the building envelope increases if the building is pressurized so that moisture control may be the dominant concern in planning pressure relationships.)

Consider air flow and pressure relationships under worst case scenarios (e.g. kitchen exhaust fans running full in cafeteria. Consider the effect on a neighboring print room, or a boiler room where backdrafting of the flue is a possibility.

Avoid underground ducts or a duct through crawl spaces where possible.

Prefer ducted returns. Non-ducted returns complicate system balancing resulting in the potential for areas of stagnant air, undesirable pressure relationships, and contamination of the return airflow.

Develop a program statement that defines the range of possible occupant densities, activities and layouts to allow the designer to plan flexibility or sufficient capacities for future changes. Specify alterations to the system that can be accommodated under the HVAC design used, and what changes to the system would be required.

Carefully analyze location of supply and return air grills for all occupied spaces, as well as the throw capacity of diffusers, and airflow pathways. Map the anticipated airflow patterns to insure proper air mixing (or plug flow airflow if that is planned). Avoid short-circuiting of supply air to return air. Also avoid dead spaces (e.g. provide for a 2-3 inch air space between the floor and workstation partitions to facilitate air circulation).

Filtration

Particle pollutants cause mucus membrane irritation and other effects, and can foul ventilation system components and reduce efficiencies. Fine particles comprise only a small portion of the total particle mass, but constitute the overwhelming majority of the number of particles. Filtering larger particles is most important for protecting equipment, while filtration of finer particles is most important for human health and comfort.

Filtration efficiency for a given filter will vary with particle size. Thus, a filter rated as 40% efficient by the ASHRAE dust spot method will have about that efficiency for large (above 2.5 microns) and very small (0.01 microns and less) but have close to zero efficiency at 0.1 to 0.5 microns.

- Specify specific filter rating in the moderate or higher efficiency range, and design system for anticipated pressure drop.
- Low efficiency filters (e.g. ASHRAE Dust Spot rating of 10%-20%), if loaded to excess, will become deformed and even “blow out”, leading to clogged coils, dirty ducts, reduced indoor air quality and greater energy use.
- Moderate efficiency filters (e.g. ASHRAE Dust Spot rating of 40%-65%) have more body, are easier to insure a tight fit, and are less subject to blow out.
- Higher efficiency filters are often recommended as a cost-effective means of improving IAQ performance while minimizing energy consumption.
- Filter installations should be designed for ease of inspection and replacement, and to minimize bypass airflow.

Air Cleaning

Air cleaning may be considered as a means of control for specific contaminants experienced from a nearby outdoor source, or an unusual indoor source. Air cleaning mediums (e.g. treated charcoal, potassium permanganate) should be chosen carefully to insure effective target contaminant removal.

Materials Evaluation and Selection

Selecting Materials

Work with manufacturers to select products with the desired emission profile, and develop a strategy to minimize building contamination during installation. Require information about emissions from manufacturers. Manufacturers have both a marketing and liability motivation to test their products. Testing laboratories and emission testing protocols are rapidly developing. In selecting materials, investigate the materials potential to pollute the indoor environment in four key areas:

1. Release of particles, fibers, or chemicals inherent in the material selected.
2. Potential ability of chemical molecules or particles in the air to adsorb (physically attached) to the material and be released later (e.g. during warm weather or when disturbed).

3. Potential for microbial growth on material surfaces.
4. Maintenance or refurbishing requirements requiring chemical treatment that can become pollution sources.

- Wet-applied" materials such as caulks, paint, adhesives, are of particular concern because of the high emission rates experienced while curing.
- Fast drying materials offer greater flexibility in developing strategies to minimize contamination of other building materials.
- Materials used in areas, which are likely to become moist, or wet (e.g. kitchens/showers, downstream from cooling coil, area around humidifier) can foster microbial growth if a carbon source is available. Easily cleaned, smooth surfaces are recommended.
- Use of fibrous material, including fiberglass insulation in ducts, requires careful consideration of the potential for soiling. Soiled fiberglass will take on moisture much more rapidly than clean fiberglass creating the potential for microbial growth. Particles provide carbon, and the fiberglass matrix provides self-sheltering surfaces for microbial growth.
- Fleecy materials covering large areas, such as carpeting, fabric upholstery, textile wall coverings, or ceiling tiles, all can adsorb chemical and particle contaminants during the finishing stage of building construction, and release it later after occupancy. When wet, these surfaces also foster microbial growth.

Strategies for Selection and Installation of Materials

- Identify target products of particular concern, considering potential emission rates, toxicity, and quantity used.
- Gather information from manufacturers, suppliers and other sources.
- Require specific testing, if necessary, of emissions over time.

Select and/or negotiate for materials with low emissions and quick decay rates where possible. Use this information to determine strategies for the sequence of installation and the ventilation strategies during installation. Negotiate pre-shipment storage techniques that accelerate emissions of partitions, carpets and similar materials prior to installation. Sometimes perforated containers can serve to facilitate off gassing during shipment.

Construction

Many IAQ problems occur as a result of poor construction practices, change orders, or field orders. Monitoring all work is critical to good IAQ.

Monitoring the Construction/Renovation Process

Monitor field orders, shop drawings, and change orders impacting IAQ specifications and designs. Check deviations from construction documents. Monitor IAQ specifications during progress by inspections, and check that products and materials specified are being used.

- Obstacles or construction debris in ventilation airflow paths.
- Proper installation of insulation, HVAC equipment, ductwork
- Monitor HVAC system testing and balancing as it occurs.
- Monitor contaminant isolation and control strategy during construction/finishing.

Emission Control During Construction/Renovation

Protect current and future occupants during construction.

- Accelerate emissions of wet products by using high ventilation.

- During high emission periods, protect workers and increase ventilation.
- Delay installation of adsorbent (fleecy) materials such as carpet, furniture, or ceiling tiles until emissions from other construction contaminants (e.g. wet product emissions) have dissipated. Otherwise, these materials will adsorb the contaminants and later release them during occupancy.
- Protect ducts from construction dust and debris. Keep ducts clean.
- Delay occupancy until emissions have subsided.
- Continue high ventilation rates for a significant period after occupancy.

Isolation of Construction/Renovation Contaminants When Occupants are Present

An isolation strategy is usually a necessary condition for effective IAQ control, but it is made more feasible to achieve when pollutant emissions are also controlled through material selection and installation strategies.

- Establish a complete physical enclosure to the construction zone.
- Seal all return ducts to insure that contaminants do not enter the HVAC system.
- Using existing and temporary exhaust fans (negative air machines) establish a containment zone under significant negative pressure (e.g., 5 to 10 Pa. or 0.02 to 0.04 w.g.). The supply air to the construction area may also need to be shut down.
- Monitor pressure relationships to insure that the containment zone is under significant negative pressure, and that the construction zone beyond the containment area is under negative pressure relative to all surrounding occupied spaces on the same and on adjacent floors.
- Insure that exhausted contaminants do not re-enter the building through open windows or the air intake of the HVAC system.
- Maintain the occupied spaces under positive pressure relative to the outside.

After Construction

Check the Building Envelope

Check the integrity of the entire building envelope by performing the following:

- Flood test flat roof systems for leaks (do not exceed design live loads).
- Inspect flashing for signs of leakage.
- Inspect doors and windows for operation and weather-stripping.
- Inspect windows and solar equipment (e.g. solar shades) for proper installation and solar angle.
- Verify that outdoor air is not entering the building through openings near loading dock or other sources of pollution.

Commissioning of HVAC System (Construction Phase)

Proper commissioning in the construction phase insures that the building is built correctly and that it works right before occupancy. See ASHRAE Guideline 1-1996, *The HVAC Commissioning Process* for detailed recommendations.

- Test and balance system.
- Test system performance under full and part load conditions.
- Test outdoor airflow at breathing zone in the occupied spaces under full and part load conditions.
- Review system operation and documentation.
- Test pressure relationships consistent with an air pressure map showing areas of planned positive and negative pressure.
- Assemble all relevant parties to discuss system; answer any questions about system sequences, set points, and operation; and review all documentation prior to

submittal.
- Insure that part of the documentation includes operating and maintenance procedures, and an air pressure map.
- Submit documentation.
- Train operational and maintenance personnel on all the operating and maintenance practices required for the particular HVAC system and other systems in the building.

Initial Occupancy After or During Construction/Renovation

Protocol for Ventilation System Operation under Initial Occupancy Conditions

Special HVAC strategies should be employed for an extended period after initial occupancy.

- Extend hours of ventilation system operation.
- Increase outdoor air fraction and operate at reduced temperatures during occupancy.
- Increase outdoor air fraction during unoccupied periods.
- Measure key contaminants such as formaldehyde and total volatile organic compounds (TVOC) as a means to judge when the HVAC system can return to normal operation.
- Run HVAC continuously and increase outdoor air fraction during first hot weather period.

HVAC Verification under Occupancy Conditions

Verify system components are all operational and system meets performance requirements under all operating conditions (full and part load) when the building is occupied.

- Verify outdoor air louvers are open and working correctly.
- Verify that all interior spaces are receiving design quantities of outdoor air.
- Verify that fans in air handling units operate continuously during occupied periods.
- Verify that all supply registers/diffusers, and return grills are open and unobstructed. Adjust diffusers to insure proper mixing and to avoid drafts on individual occupants.
- Verify the operation of all VAV boxes according to design.
- Verify that local exhaust grilles and hoods are operating correctly.
- Check for backdraft from all combustion appliances under worst case scenarios.
- Check air pressure relationships according to original plans.

Indoor Air Quality Evaluation

Evaluate IAQ by conducting a building walkthrough to identify problems. Talk to occupants to identify problems.

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: Managing for Indoor Air Quality

The purpose of this module is to help you establish a management program that contains all the appropriate elements needed to manage a building for good IAQ.

Contents

- **Assignments and Training**
  - Assign an IAQ Manager
  - Train Supervisors and Staff
- **Establishing an Adequate IAQ Baseline**
  - Update Building Records Important to an IAQ Management Program
  - Conduct a Baseline Building Audit to Determine IAQ Status in the Building
  - Fix Problems Identified in Building Audit (Special IAQ)
- **Establish Written Plans and Protocols**
  - Source Management Protocols
  - Written Maintenance and Housekeeping Plans
  - Content of Plans
- **Establish a Communications Program**
  - Purpose
  - Critical Areas of Responsibility and Communication
  - Establish a Procedure for Responding to IAQ Complaints
    - Principles of Complaint-Response Program
  - Content of Complaint-Response Program
  - Information for Occupants
  - Diagnostic Procedures
  - Notify Occupants of Major Activities
- **Market and Budget Your IAQ Program**
  - Marketing Your Building's IAQ Program
  - Develop an IAQ Expense Budget

I-BEAM Text Modules

- Fundamentals of IAQ in Buildings
- Heating, Ventilation, and Air-conditioning (HVAC)
- IAQ Maintenance and Housekeeping Programs
- Indoor Air Quality and Energy Efficiency
- Diagnosing and Solving Problems
- Renovation and New Construction
- **Managing for Indoor Air Quality**
- IAQ Budgets and Accounts

- Overview of I-BEAM
- Overview of Text Modules
- Overview of Visual Reference Modules
- IAQ Budgets and Accounts
- I-BEAM Forms

Managing for Indoor Air Quality
(PDF, 14 pp, 79KB)

You will need Adobe Reader to view some of the files on this page. See EPA's PDF page to learn more.

Indoor Air Quality (IAQ)

Assignments and Training

Assign an IAQ Manager

Determine who is responsible and accountable for IAQ in the building. Assign a senior person and provide him/her with sufficient authority to develop and implement a comprehensive indoor air quality management plan.

Using I-BEAM and other comparable training programs, make sure that the IAQ manager is familiar with the principals of IAQ and the elements of a good IAQ management plan. The IAQ manager could be responsible for:

- Insuring up to date building drawings and records.
- Staff IAQ training.
- Coordinating a building walkthrough and IAQ building profile.
- Developing/reviewing maintenance and housekeeping plans for IAQ.
- Review contracts and negotiations with contractors for IAQ related specifications (e.g., maintenance or housekeeping contracts, renovation contracts, pest control contracts).
- Developing/maintaining an occupant complaint-response system.
- Investigating occupant complaints.
- Communicating with tenants/occupants about building activities, and about occupant/tenant responsibilities for IAQ.

Train Supervisors and Staff

In a well-functioning IAQ program, IAQ program functions are established and key personnel have clearly defined IAQ responsibilities. All personnel understand the fundamentals of IAQ and are trained to incorporate IAQ in their daily work. Key personnel include the:

- Building Manager
- Building Engineer
- HVAC Personnel
- Building Maintenance Personnel
- Housekeeping Personnel
- Pest Control Personnel
- Purchasing
- Contractors of all sorts
- Administrative personnel responsible for record keeping, contract management and related tasks.

Information on additional training resources is available from EPA (link) and information of regional training resources in the private sector may be obtained from EPA Regional Offices (link).

Establishing an Adequate IAQ Baseline

Update Building Records Important to an IAQ Management Program

Develop an organized system to obtain and maintain the following building records:

- “As built” blueprints, including modifications to reflect current conditions.
- Up-to-date drawings of all tenants' build outs and interior renovations.
- Records of major space use changes not reflected in original design.
- Drawings of pressure relationships.

- Operating and Maintenance Plans and Schedules.
- Historical Occupant IAQ complaint logs (if available).
- Inventory of products and materials that are sources of pollutants, with MSDS sheets and related information.

I-BEAM provides convenient forms for tracking progress in developing and maintaining some building records. Documents that may be useful in organizing these records include:

- Construction documents
- Commissioning reports
- Operating manuals
- HVAC maintenance records
- Remodeling and Renovation records
- Records of equipment modifications/replacement
- Records of complaints

Conduct a Baseline Building Audit to Determine IAQ Status in the Building

When first starting an IAQ program, conduct a whole building walkthrough to record the status of all IAQ parameters identified in I-BEAM. Take simple measurements of pressure relationships and air flow patterns as may be appropriate, and record where more detailed measurements may be needed at a later date to complete the basic profile. Use I-BEAM forms to assist in recording basic conditions of:

- Occupied spaces
- Mechanical Systems
- Building Exterior

Repeat the baseline audit periodically.

Fix Problems Identified in Building Audit (Special IAQ)

When problems are identified in the baseline audit, they may constitute special IAQ expenses - i.e. not regularly recurring expenses but those designed to upgrade the building to minimal IAQ conditions. For these expenses, appropriate work orders should be entered so that the problems are fixed. Managers should plan and budget for the remediation of major problems requiring significant expenditure. I-BEAM can assist in planning and budgeting.

Establish Written Plans and Protocols

Source Management Protocols

Pollution sources with extremely high potential to cause indoor air quality problems require that specific written protocols be established to manage those sources. These significant sources of pollution include:

- Remodeling and Renovation
- Painting
- Pest Control
- Shipping and Receiving
- Smoking

The IAQ program should include written protocols for managing each of these sources. Protocols for other sources that are dominant in any building should also be developed using the principles contained in I-BEAM.

Written Maintenance and Housekeeping Plans

Written maintenance and housekeeping plans are important for several reasons:

- To train and guide building personnel as part of the IAQ management plan.
- To negotiate contracts for housekeeping and maintenance activities that are conducive to good IAQ.
- To establish an IAQ budget.
- To document key management components of the IAQ program for marketing and for liability purposes.

Content of Plans

Suggested maintenance and housekeeping program principles, detailed tasks and task schedules important to IAQ are available in I-BEAM and can be used as a useful starting point in developing written plans and work schedules.

Establish a Communications Program

Purpose

The purpose of communication protocols is to identify the purposes and objectives of a communication procedure. Specifically:

- To clarify the responsibilities of facility managers, staff, contractors, and occupants in maintaining a safe and comfortable indoor environment.
- To respond effectively to occupant complaints.
- To avoid mistrust and misunderstandings.
- To prevent situations in which distrust between occupants and management result in disruptive, contentious, and costly remedies including legal remedies that could have been avoided.
- To help occupants improve their work environment through positive contributions.

Critical Areas of Responsibility and Communication

Develop an understanding of general responsibilities and communication needs. Provide information to tenants and occupants about what they can do to insure good IAQ in the building. Generic guidance is available in I-BEAM's Resource Menu, or on the EPA IAQ website.

Establish a Procedure for Responding to IAQ Complaints

Principles of Complaint-Response Program

Three general principles of complaint response are:

1. Every complaint should be addressed promptly and tracked until it is resolved.
2. There should be follow-up of the complaint after it is resolved to make sure the resolution is permanent.
3. Records of the complaint, the investigation, and the resolution should be kept on file. Record keeping should be done to facilitate recognition of patterns.

Content of Complaint-Response Program

An IAQ complaint-response procedure would involve the following:

- Log of complaints.
- Method of collecting information from complaining occupant.
- Provisions for confidentiality.
- Assignment of responsibilities of in house staff.
- Provisions for obtaining outside expertise when needed.
- Diagnostic procedures.
- System for implementing solutions.
- Feedback and information as to progress for the complaining occupant.
- Follow-up to insure that remediation is effective.
- Recordkeeping procedures.

Information for Occupants

Building occupants should be informed about the complaint-response procedure. Information should include:

- Management’s policy for responding to complaints and commitment to occupant’s health and safety.
- Contact persons and telephone numbers to call in complaints.
- How to obtain forms and where to submit forms for written complaints.
- Assurances of confidentiality.
- Procedures for diagnosing problems and resolving complaints.
- Names and phone numbers of persons to call for more detailed information.

For major complaints involving large numbers of individuals, every occupant will have an interest in progress during an investigation. Develop a procedure to keep all occupants informed which includes:

- Description of the problem and definition of the complaint area.
- Progress of investigation.
- Factors that have been evaluated and ruled out as causes or contributors.
- Expected length of investigation.
- When occupants will receive further information.
- What occupants can do to help.

Diagnostic Procedures

Follow the diagnostic procedure guidance contained in I-BEAM.

Notify Occupants of Major Activities

Develop notification procedures for any renovation, remodeling, pest control, HVAC operational disruptions, painting, or other activities that could cause temporary IAQ problems. Also inform tenants and occupants about activities designed to improve IAQ.

Market and Budget Your IAQ Program

Marketing Your Building's IAQ Program

A good IAQ management program is a negotiating tool to keep existing tenants or attract new tenants. Develop an IAQ management plan, and use it to maintain tenant satisfaction. Surveys by BOMA and IFMA place HVAC, Thermal Comfort, and IAQ among the top 5 leading complaints and can affect office moves and changes. Use your IAQ program to market and promote your building to prospective tenants. Your responsiveness to IAQ can be the difference between gaining (or retaining) a tenant or losing a tenant to a close competitor.

About half the occupants of commercial office-buildings report reduced productivity due to poor IAQ. This includes individuals who report only minor loss, as well as individuals in buildings whose IAQ is very poor and whose reported loss is substantial. When averaged among all offices, the loss is approximately 3 percent. Tenants may wish to consider the productivity implications of improved IAQ. Landlords may wish to consider the revenue implications of improved occupancy and occupancy satisfaction.

Develop an IAQ Expense Budget

Managing for IAQ and energy efficiency is often more a matter of doing it right within the current budget than increasing expenditures beyond existing budget. Use I-BEAM to identify IAQ activities and develop an IAQ expense budget.

IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: IAQ Budgets and Accounts Module

This module is *interactive* on the CD-version (which is no longer available for ordering or to download). This module allows you to catalogue all of your IAQ activities and IAQ expenses, and assess the impact of those activities on your bottom line. Further, you can use this module to document your IAQ actions and expenses, and to develop a marketing plan. By marketing IAQ, you take advantage of the evidence that IAQ affects employee moral and performance, and the evidence that an IAQ program can be an attractive feature for existing and prospective tenants.

- What Can I Do With This?
  - Expenses
  - Revenues
  - Productivity
- Why Should I?
  - Occupants
    - Tenants Want Good IAQ But Are Not Yet Negotiating For It
    - BOMA Survey: Office Tenant Moves and Changes (1988)
    - IFMA Survey: Top 5 Complaints of Corporate Tenants (1991)
- Market Your IAQ
- How Do I?

IAQ Budgets and Accounts (PDF, 14 pp, 79KB)

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Indoor Air Quality (IAQ)

What Can I Do With This?

Occupants and tenants are becoming more interested in IAQ. With this module, you can document your IAQ program activities, tally up your expenditures, and assess the potential productivity and revenue impacts of your IAQ program.

Here is how this model works.

Expenses

- Catalogue your IAQ activities in HVAC maintenance, general maintenance, housekeeping, remediation, and capital expenses.
- Identify and breakdown the cost of each activity for this year and over the long term.
- Allocate IAQ activity expenses between those which are new, and those which are already part of your baseline budget.
- Develop an IAQ budget and identify the impact of IAQ expenses on your total budget.

Revenues

- Assess the potential for retaining existing tenants because of your IAQ program and your marketing efforts.
- Estimate the value of potentially improved tenant retention on leasehold expenses and net revenues

Productivity

- Assess the potential impact good IAQ may have on the morale and productivity of your building occupants.
- Determine the value of potential productivity improvements to occupants, and the resulting rate of return on your IAQ investment.
- Develop data to help market your IAQ program to prospective tenants or to your own management.

Why Should I?

So what's all this about IAQ? In the mid 1970s, nobody heard about IAQ. Now, you can't open a building-related professional magazine without seeing some article about IAQ.

- New diseases with names like *Sick Building Syndrome* and *Building Related Illness* all related to IAQ have emerged.
- Occupants and tenants are suing architects, builders, and building owners for health and business costs associated with poor IAQ.
- Industrial hygienists can now acquire a specialty certification in IAQ.
- Guidelines, websites, chat lines, and other information resources proliferate, and the market for IAQ consultants is growing.
- Major HVAC equipment manufacturers now offer solutions to IAQ problems. From duct cleaners to air cleaners, ionizers and air purifiers–everyone wants a piece of the pie.
- ASHRAE has developed an IAQ ventilation standard. OSHA has proposed an IAQ regulation. And EPA is publishing major guidance documents like I-BEAM.
- Five to ten major domestic and international conferences a year are devoted solely to IAQ.

Why? Because occupants, tenants, and building owners, health authorities, and lawyers are beginning to take notice.

Occupants

Why do occupants care? Consider the following:

- Failure to follow simple risk avoidance guidelines in the design, construction, and operational systems of buildings is the prime cause of “sick buildings” or complaint buildings, where illness rates are 2 - 6 times higher than average for symptoms of the lower respiratory tract, 3-5 times higher than average for inflammation or irritation of mucous membranes, and 2-3 times higher than average for central nervous system health effects.
- Substantial performance losses can be subtle and occur even though people do not

overtly complain. Poor IAQ increases absentee rates and loss of human performance while at work. About half of surveyed office workers complain that poor IAQ accounts for some productivity loss at work. The average reported loss for all workers is approximately 3%. This includes those who report no loss, those that report a modest loss, and those whose IAQ is very poor and whose loss is reported to be substantial.
- Several major IAQ lawsuits in the past decade have resulted in multimillion dollar settlements, where everyone from the builders, the equipment manufacturers, and the building owners were named as defendants.
- Estimates of annual savings that could be achieved by following good practice guidelines which are incorporated in I-BEAM range from $50 billion to $150 billion.

So occupants care and they expect to get good IAQ. Breathing clean air is considered a right, not a privilege.

Tenants Want Good IAQ But Are Not Yet Negotiating For It

Tenants desire for improved indoor air quality is widespread. Two independent surveys of major building tenants place indoor air quality and component issues of thermal comfort and HVAC performance high on the list of major tenant complaints. Consider the results of surveys by both BOMA and IFMA.

BOMA Survey: Office Tenant Moves and Changes (1988)

Worst Problem	% of Responses
HVAC and Indoor Air Quality	30%
Elevators	12%
Building Design	7%
Loading Docks	6%
All Other	45%

Source: Office Tenant Moves and Changes: Why Tenants Move, What They Want, Where they Go. Building Owners and Managers Association International. Washington D.C. 1988.

IFMA Survey: Top 5 Complaints of Corporate Tenants (1991)

Ranking	Complaint
1st	Too Hot
2nd	Too Cold
3rd	Storage and Filing Space
4th (tie)	Indoor Air Quality
4th (tie)	Janitorial Service

If tenants care, why are they silent during lease negotiations? It seems that tenants look for, and owners market their space according to its location, its appearance, parking, and other items that are visible and tangible even though they identify such items as IAQ, thermal comfort and janitorial services as major problems. So why aren't they asking for good IAQ?

Turn this question around. What would you expect a tenant to negotiate for if he/she wanted guarantees of good IAQ? IAQ doesn't have a convenient metric or tangible quality. It is not like parking, or location, or elevator services which are easily described. Rather, it is wrapped into the fabric of the design, construction, operation, and maintenance of the building in hundreds of different ways, as is described in I-BEAM. So even if tenants want it provided, how would you expect them to negotiate for it?

Traditionally, products like IAQ become negotiable items when they are represented by specific protocols or standards of practice. Unfortunately, IAQ protocols have not been available. However, much has been learned over the past 15 years and guidance such as I-BEAM or standards such as ASHRAE Standard 62-1999 are beginning to provide specific protocols that tenants can ask for. The process is just beginning. So tenants who look at I-BEAM or similar guidance and who become familiar with the ASHRAE Standards will be asking for items such as adequate outdoor air flow, documented source control protocols, IAQ stewardship principles in housekeeping, and good HVAC preventive maintenance program for IAQ related items. They will want to know *specifically* what you are doing about IAQ. Are you prepared to present your IAQ program?

Market Your IAQ

But why wait for tenants to ask for your IAQ package? Owners of products don't wait for customers–they take the initiative to market their product to gain a competitive edge. Now that you have used I-BEAM to develop a specific IAQ program, you can use I-BEAM again to document it, package it, cost it out, and market it.

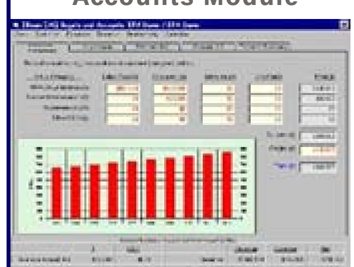
Will tenants respond? Parking, location and appearance will always mean a lot, but in a competitive market, knowing that the building will support the health and performance of their workers and that the building manager is prepared to respond knowledgeably to a potential IAQ problem is an attractive feature.

And what if tenants do begin to ask for your IAQ package? How will you respond? I-BEAM can give you the tools. Remember, managing for IAQ is often more a matter of doing it right within your budget than increasing expenditures beyond your budget. So use I-BEAM to achieve a cost-effective, tailor made IAQ program for your building.

How Do I?

The **Budget and Accounts module** provides an easy framework for developing, assessing and modifying your IAQ budget. Here the steps you can follow.

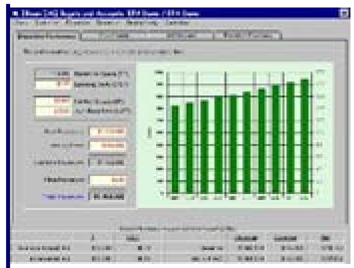
I-BEAM Budgets and Accounts Module



Expenses Example
Click on the graphic for a slightly larger version

1. **Click on Building Parameters.**
   - Enter the name and size of your building or set of buildings. Name a scenario and choose an inflation rate, a start year and the number of years you wish for your analysis. If you choose, you can also enter names for "Non-Categorized" and "Other" expenses that appear on the baseline expense screen (See Expenses in #2 below).
2. **Click on Expenses (see graphic at right for example).**
   - Enter the annual operating and annual capital expenses that you budget for by the major categories provided. These will be saved as your baseline annual

expenses. Some expenses that you already undertake but that are important for IAQ will be included in your baseline. If you choose, you can identify these separately later in the IAQ expense windows. You can break down your baseline expenses by labor and material categories, or you may enter just the totals in the non-categorized column. Enter the annual budget for capital expenses and the annual budget for extraordinary expenses (e.g., unusually large repairs) that you regularly budget for, but that are not included elsewhere.



Revenues Example
Click on the graphic for a slightly larger version

- The accounts bar at the bottom of every screen will record the annual average expenses and revenues over the years you have specified (in constant start-year dollars). Thus, your total average annual baseline expense will be recorded on the accounts bar. This bar keeps a running total of your expenses and revenues as you make changes on each screen.

3. **Click on Adjustments.**

   - This window gives you the opportunity to adjust your baseline for particular years based on anticipated extraordinary activities in any years that you had not included in your annual average baseline budget. I-BEAM will automatically calculate the average annual expense in base year dollars and insert it into your baseline budget.

4. **Click on Standard IAQ.**

   - You undoubtedly already conduct many of the activities listed in I-BEAM as being important to IAQ. This screen allows you to consider the bottom line impact of additional or "incremental" IAQ activities you would like to consider based on your walkthrough inspection or I-BEAM suggestions. In addition, as an optional feature, you may also record your current IAQ budget (IAQ activities already included in your baseline). Since identifying all IAQ activities and their expenses, both current and incremental, may be tedious, it is suggested that you deal with your incremental IAQ activities only at first. Only the incremental activity expenses are used to calculate bottom line impacts of contemplated IAQ activities. The total IAQ activities and expenses (included in baseline plus incremental activities) is useful for documenting your complete IAQ program. This may be important for marketing or for legal documentation, or for other purposes.

   - This screen provides IAQ activity "tickler" lists in four categories: IAQ Maintenance, IAQ Protocols and Procedures, IAQ Housekeeping, and IAQ Administrative Expenses. Click on each category and the "View Sample Activities" bar for each list. For your convenience, each list identifies IAQ activities described in I-BEAM to help you in using this window.

   - You may highlight an item on the tickler list and then click on "Include Item in my IAQ Activity List" or you may create your own custom activity with the "Add Custom Activity" bar. On the pop up window, name or modify the name of the activity as needed, and identify an account number. Record the expenses or anticipated expenses for this item. You may do this in detail, or simply provide totals in the "Non-Categorized" boxes. At a minimum, you must record the expense you are contemplating as an addition or "incremental expense" to your IAQ program. For example, you may wish to upgrade the HVAC filtration from low to medium efficiency. At a minimum, record that expense under "incremental IAQ". On the accounts bar at the bottom of the screen, this incremental expense will be added to your annual average IAQ expense, your incremental IAQ expense, and your total with IAQ expense.

- You may also record the total baseline expense for the item in question, and the value of that portion of the baseline expense that you wish to identify as an IAQ activity.
- For convenience, you may also record your current baseline expense for the in question (e.g., filters). To this, I-BEAM will add the incremental IAQ expense and show you the total expense for this item in the last column. This is solely for your convenience, but does not affect any calculations or reports in I-BEAM.
- In addition, if you choose, you may also allocate some portion of this baseline expense to your IAQ program and record that value in the IAQ portion of the pop-up window under "Included in Baseline". The IAQ "included in baseline" plus the "incremental IAQ" expense will be added to obtain your "total IAQ" expenses. This would add an activity and expense to your overall IAQ program budget, but would not affect the baseline budget, and would not affect the bottom line impact assessment you do in I-BEAM since that assessment relies solely on the incremental expenses and incremental benefits from additional activities. Each activity that you enter will be recorded in I-BEAM. You will be able to review and print these out from the Reports screen in the Overview window.
- A running total of the IAQ expenses and the total incremental IAQ expenses are recorded on the bottom line summary bar at the bottom of the screen. If you are just recording incremental activities at this time, the IAQ expense total will be understated and be equal to your incremental IAQ expense.

5. **Click on Special IAQ.**
   - Record here activities which do not recur annually, but may either be extraordinary expenses designed, for example, to fix problems found in your baseline IAQ audit, or capital expenses which will require financing. I-BEAM will incorporate these into the bottom line calculations.
6. **Click on Expense Summary.**
   - This window summarizes your expenses for each year. Use the slider bar to identify the year of interest.
7. **Click on Revenue (for leased space) (see graphic at right for example).**
   - Enter your average rental rate, lease expenses, and other revenues you wish to record as annual baseline values.
8. **Click on Adjustments.**
   - Record any adjustments to revenue for particular years due to unusual events you have not included in the annual average baseline revenues.
9. **Click on IAQ Impact.**
   - Record differences in rental rates and lease expenses associated with renewing a lease for an existing tenant versus obtaining a new tenant.
   - Identify the proportion of leases retained in the baseline, and the potential increase in the proportion of retained leases that might result from your establishing and marketing an IAQ program.
   - This screen now records the potential increase in revenue due to IAQ, and the

cost-benefit results of your IAQ program based on potential revenue gains. You can use the slider bar to determine what increases in tenant retention would be necessary to break even, given your incremental IAQ expenses.

10. **Click on Rental Summary.**

    - Review your rental income, with and without IAQ for each year.
    - The accounts bar at the bottom of each screen now records the annual average expenses and revenues with and without IAQ (in constant start-year dollars).

11. **Click on Productivity.**

    - Enter the total wages of employees affected by this IAQ program.
    - Enter anticipated or potential productivity improvement due to IAQ.
    - This screen now records the productivity value and the cost-benefit results of your IAQ program based on potential productivity gains.

12. **Use the results.**

    - Click on Overview and then on "graphics" to obtain graphic presentations of your accounts, and click on "reports" which will provide detailed reports of your IAQ program based on your inputs. You can use these features to market your program to potential tenants, or to develop proposals for an IAQ budget to upper management.
    - Go to the file menu and save this scenario under an appropriate name.

13. You can create other scenarios for this building or set of buildings using other parameters and input values.