Appendix A:
Common IAQ Measurements - A General Guide

The following is a brief introduction to making measurements that might be needed in the course of developing an IAQ profile or investigating an IAQ complaint. Emphasis has been placed on the parameters most commonly of interest in non-research studies, highlighting the more practical methods and noting some inappropriate tests to avoid. Most of the instruments discussed in this section are relatively inexpensive and readily available from many local safety supply companies. Consult the guidance in *Section 6* on pages 72-73 before determining whether to proceed with air sampling.

OVERVIEW OF SAMPLING DEVICES

Air contaminants of concern in IAQ can be measured by one or more of the following methods:

Vacuum Pump:
A vacuum pump with a known airflow rate draws air through collection devices, such as a *filter* (catches airborne particles), a *sorbent tube* (which attracts certain chemical vapors to a powder such as carbon), or an *impinger* (bubbles the contaminants through solution in a test tube). Tests originated for industrial environments typically need to be adjusted to a lower detection limit for IAQ work. Labs can be asked to report when trace levels of an identifiable contaminant are present below the limit of quantification and detection.

In adapting an industrial hygiene sorbent tube sampling method for IAQ, the investigator must consider at least two important questions. First: are the emissions to be measured from a product's end use the same as those of concern during manufacturing? Second: is it necessary to increase the air volume sampled? Such an increase may be needed to detect the presence of contaminants at the low concentrations usually found in non-industrial settings. For example, an investigator might have to increase sampling time from 30 minutes to 5 hours in order to detect a substance at the low concentrations found during IAQ investigations. In cases where standard sampling methods are changed, qualified industrial hygienists and chemists should be consulted to ensure that accuracy and precision remain acceptable.

Direct-reading Meter:
Direct-reading meters estimate air concentrations through one of several detection principles. These may report specific

SELECTING MEASUREMENT DEVICES

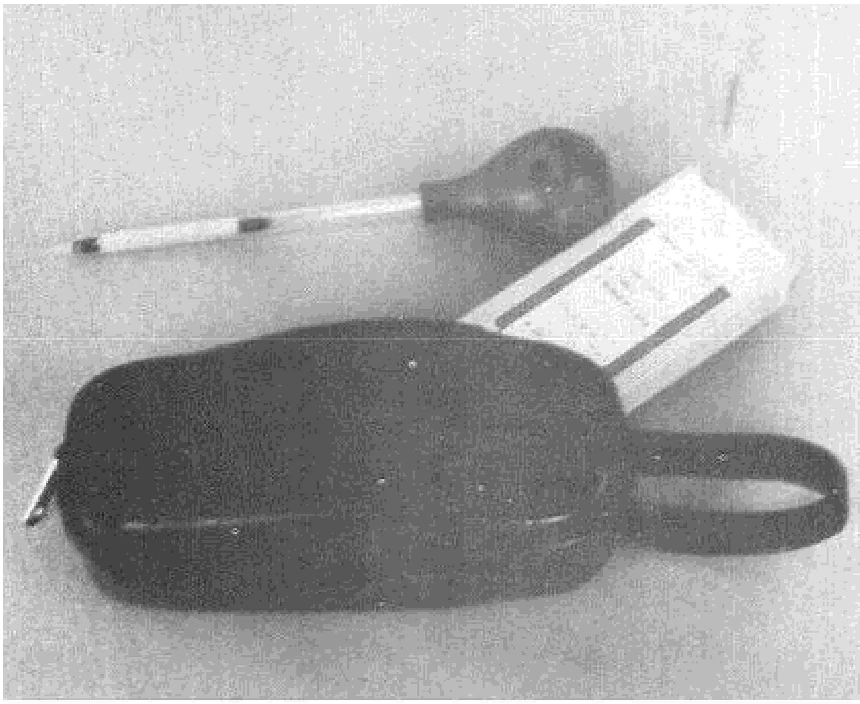
The growing interest in indoor air quality is stimulating the development of instruments for IAQ research and building investigations. As you evaluate the available measurement devices, it may be helpful to consider the following criteria:

Ease of use
- portability
- direct-reading vs. analysis required
- ruggedness
- time required for each measurement

Quality assurance
- availability of service and customer support
- maintenance and calibration requirements

Output
- time-averaged vs. instantaneous readings
- sensitivity
- compatibility with computer or data logging accessories

Cost
- single use only vs. reusable
- purchase vs. rental



Above: A smoke tube, which is one type of chemical smoke device. Used to observe patterns of air movement and the direction (negative or positive) of pressure differences. Below: A microman-ometer. Used for measuring pressure differentials to learn about airflow. Provides quantitative data, as compared to the qualitative information provided by chemical smoke.

chemicals (e.g., CO_2 by infrared light), chemical groups (e.g., certain volatile organics by photoionization potential) or broad pollutant categories (e.g., all respirable particles by scattered light). Detection limits and averaging time developed for industrial use may or may not be appropriate for IAQ.

Detector tube kit:
Detector tube kits generally include a hand pump that draws a known volume of air through a chemically treated tube intended to react with certain contaminants. The length of color stain resulting in the tube correlates to chemical concentration.

Personal monitoring devices:
Personal monitoring devices (sometimes referred to as "dosimeters") are carried or worn by individuals and are used to measure that individual's exposure to particular chemical(s). Devices that include a pump are called "active" monitors; devices that do not include a pump are called "passive" monitors. Such devices are currently used for research purposes. It is possible that sometime in the future they may also be helpful in IAQ investigations in public and commercial buildings.

SIMPLE VENTILATION/COMFORT INDICATIONS

Thermal Comfort: Temperature and Relative Humidity

The sense of thermal comfort (or discomfort) results from an interaction between temperature, relative humidity, air movement, clothing, activity level, and individual physiology. Temperature and relative humidity measurements are indicators of thermal comfort.

Methodology

Measurements can be made with a simple thermometer and sling psychrometer or with electronic sensors (e.g., a thermo-hygrometer). Accuracy of within + or - 1°F is recommended for temperature measurements. For each measurement, time should be allowed for the reading to stabilize to room conditions. Refer to the specifications for the measuring device; some take several minutes to stabilize. Electronic relative humidity (RH) meters must be calibrated frequently.

Indoor relative humidity is influenced by outdoor conditions. A single indoor measurement may not be a good indication of long-term relative humidity in the building. Programmable recording sensors can be used to gain an understanding of temperature or humidity conditions as they change over time.

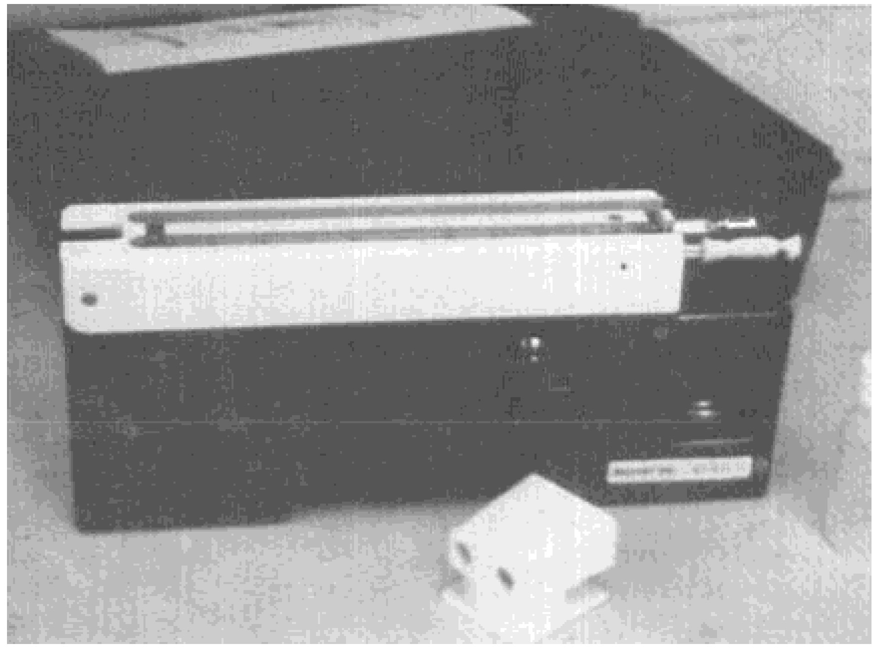
Using the Results

Temperature and humidity directly affect thermal comfort. They may also provide indirect indications of HVAC condition and the potential for airborne contamination from biological or organic compounds. There is considerable debate among researchers, IAQ professionals, and health professionals concerning recommended levels of relative humidity; however, the humidity levels recommended by different organizations generally range between 30% and 60% RH.

Comparison of indoor and outdoor temperature and humidity readings taken during complaint periods can indicate whether thermal discomfort might be due to extreme conditions beyond the design capacity of HVAC equipment or the building envelope.

Measure next to thermostats to confirm calibration. Measure at the location of complaints to evaluate whether or not temperature and humidity at that location are within the comfort zone (see Figure 6-2 on page 57).

Readings that show large variations within the space may indicate a room air distribution or mixing problem. Readings that are highly variable over time may indicate control or balance problems with the HVAC systems.



A psychrometer. Used to measure dry bulb and wet bulb temperatures and to determine relative humidity based upon a psychometric chart. The NIOSH protocol for indoor air investigations always includes measurement of indoor and outdoor relative humidity. There are two types of psychrometers: aspirated (with a fan) or sling (without a fan).

Tracking Air Movement with Chemical Smoke

Chemical smoke can be helpful in evaluating HVAC systems, tracking potential contaminant movement, and identifying pressure differentials. Chemical smoke moves from areas of higher pressure to areas of lower pressure if there is an opening between them (e.g., door, utility penetration). Because it is heatless, chemical smoke is extremely sensitive to air currents. Investigators can learn about airflow patterns by observing the direction and speed of smoke movement. Puffs of smoke released at the shell of the building (by doors, windows, or gaps) will indicate whether the HVAC systems are maintaining interior spaces under positive pressure relative to the outdoors.

Methodology

Chemical smoke is available with various dispensing mechanisms, including smoke “bottles,” “guns,” “pencils,” or “tubes.” The dispensers allow smoke to be released in controlled quantities and directed at specific locations. It is often more informative to use a number of small puffs of smoke as you move along an air pathway rather than releasing a large amount in a single puff. (*Note:* Avoid direct inhalation of chemical smoke, because it can be irritating. Do not release smoke directly on smoke detectors.)

Using the Results

Smoke released mid-room: Observation of a few puffs of smoke released in mid-room or mid-cubicle can help to visualize air circulation within the space. Dispersal of smoke in several seconds suggests good air circulation, while smoke that stays essentially still for several seconds suggests poor circulation. Poor air circulation may contribute to sick building syndrome complaints or may contribute to comfort complaints even if there is sufficient overall air exchange.

Smoke released near diffusers, grilles: Puffs of smoke released by HVAC vents give a general idea of airflow. (Is it in or out? Vigorous? Sluggish? No flow?) This is helpful in evaluating the supply and return system and determining whether ventilation air actually reaches the breathing zone. (For a variable air volume system, be sure to take into account how the system is designed to modulate. It could be on during the test, but off for much of the rest of the day.) "Short-circuiting" occurs when air moves relatively directly from supply diffusers to return grilles, instead of mixing with room air in the breathing zone. When a substantial amount of air short-circuits, occupants may not receive adequate supplies of outdoor air and source emissions may not be diluted sufficiently.

Carbon Dioxide (CO_2) as an Indicator of Ventilation

CO_2 is a normal constituent of the atmosphere. Exhaled breath from building occupants is an important indoor CO_2 source. Indoor CO_2 concentrations can, under some test conditions, provide a good indication of the adequacy of ventilation. Comparison of peak CO_2 readings between rooms, between air handler zones, and at varying heights above the floor, may help to identify and diagnose various building ventilation deficiencies.

Methodology

CO_2 can be measured with either a direct-reading meter or a detector tube kit. The relative occupancy, air damper settings, and weather should be noted for each period of CO_2 testing.

CO_2 measurements for ventilation should be collected away from any source that could directly influence the reading (e.g., hold the sampling device away from exhaled breath). Individual measurements should be short-term. As with many other measurements of indoor air conditions, it is advisable to take one or more readings in "control" locations to serve as baselines for comparison. Readings from outdoors and from areas in which there are no apparent IAQ problems are frequently used as controls. Outdoor samples should be taken near the outdoor air intake.

Measurements taken to evaluate the adequacy of ventilation should be made when concentrations are expected to peak. It may be helpful to compare measurements taken at different times of day. If the occupant population is fairly stable during normal business hours, CO_2 levels will typically rise during the morning, fall during the lunch period, then rise again, reaching a peak in mid-afternoon. In this case, sampling in the mid- to late-afternoon is recommended. Other sampling times may be necessary for different occupancy schedules.

Using the Results

Peak CO_2 concentrations above 1000 ppm in the breathing zone indicate ventilation problems. Carbon dioxide concentrations below 1000 ppm generally indicate that ventilation is adequate to deal with the routine products of human occupancy.

However, there are several reasons not to conclude too quickly that a low CO_2 reading means no IAQ problem exists. Problems can occur in buildings in which measured CO_2 concentrations are below 1000 ppm. Although CO_2 readings indicate good ventilation, for example, if strong contaminant sources are present, some sort of source control may be needed to prevent IAQ problems. Errors in measurement and varying CO_2 concentrations over time can also cause low readings that may be misleading.

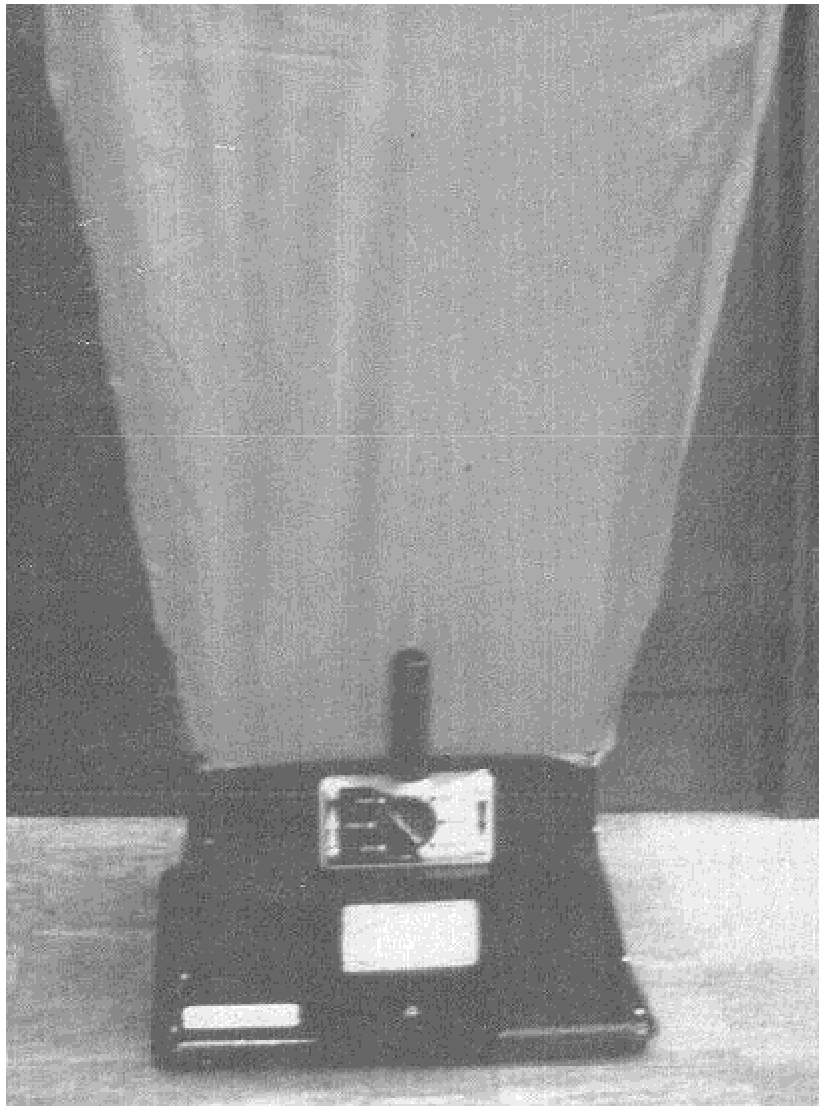
Elevated CO_2 may be due to various causes alone or in combination, such as: increased occupant population, air exchange rates below ASHRAE guidelines, poor air distribution, and poor air mixing. A higher average CO_2 concentration in the general breathing zone (at least two feet from exhaled breath) than in the air entering return grilles is an indication of poor air mixing. Smoke tubes and temperature profiles will help to clarify air circulation patterns.

If CO_2 measurements taken before the occupied period begins are higher than outdoor readings taken at the same time, there may be an operating problem with the HVAC system. Potential problems include the following:

- ventilation terminated too early the evening before (as compared with the occupancy load on the space)
- combustion by-products from a nearby roadway or parking garage are drawn into the building
- a gas-fired heating appliance in the building has a cracked heat exchanger

Outdoor CO_2 concentrations above 400 ppm may indicate an outdoor contamination problem from traffic or other combustion sources. Note, however, that detector tubes cannot provide accurate measurements of CO_2 in hot or cold weather.

Measuring Airflow

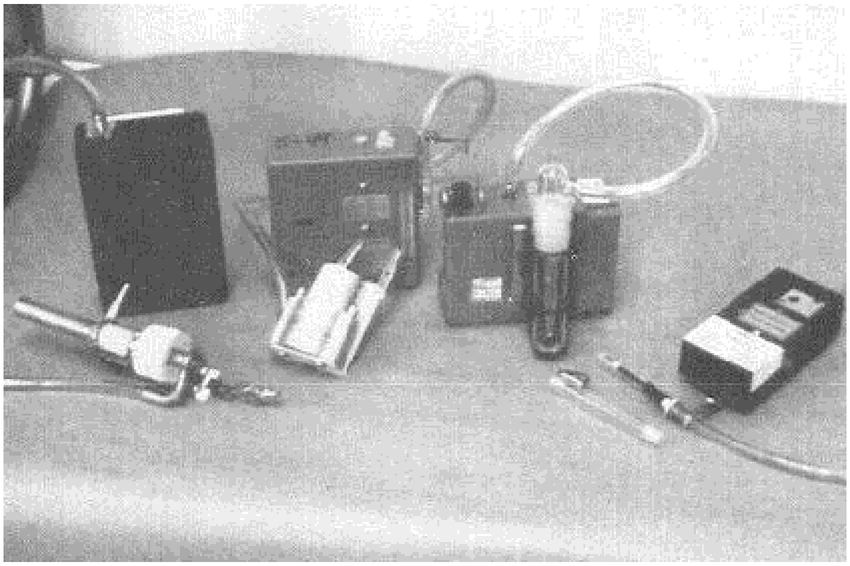


A flow hood. Used to measure the total air flow (outdoor plus recirculated air) from a diffuser.

Measurements of airflow allow investigators to estimate the amount of outdoor air that is entering the building and to evaluate HVAC system operation. The most appropriate measurement technique depends on the characteristics of the measurement location.

Methodology

Airflow quantities can be calculated by measuring the velocity and cross-sectional area of the airstream. For example, if air is moving at 100 feet per minute in a 24" x



A vacuum pump with attachments for sampling with a filter, a sorbent tube, and an impinger. Use in a non-industrial setting may require a larger volume of air. Consult with qualified industrial hygienists and chemists if adapting sampling methods.

12" duct, the airflow is:

100 feet/minute x 2 square feet duct area = 200 cubic feet/minute

Air velocity can be measured with a pitot tube or anemometer. Air velocity within an airstream is likely to vary considerably. For example, it is extremely difficult to measure air velocity at supply diffusers because of turbulence around the mixing vanes. The best estimates of air velocity can be achieved by averaging the results of a number of measurements. ASTM Standard Practice D 3154 provides guidance on making such measurements. This method is available from ASTM. (See *Appendix G* for ASTM's address and phone number.) The cross-sectional area of the airstream is sometimes easy to calculate (e.g., in a straight run of rectangular ductwork), but can be very complicated at other locations such as mixing boxes or diffusers.

Flow hoods can be used for direct measurement of airflows at locations such as grilles, diffusers, and exhaust outlets. They are not designed for use in ductwork.

Using the Results

Airflow measurements can be used to determine whether the HVAC system is operating according to design and to identify potential problem locations. Building investigations often include measurements of outdoor air quantities, exhaust air quantities, and airflows at supply diffusers and return grilles.

Estimating Outdoor Air Quantities

Outdoor air quantities can be evaluated by measuring airflow directly. Investigators often estimate the proportion of outdoor air quantities using techniques such as thermal mass balance (temperature) or CO_2 measurements. Estimation of outdoor air quantity using temperature measurements is referred to as "thermal balance" or sometimes "thermal mass balance."

Thermal Balance: Methodology

Use of this test requires the following conditions:

1. Airstreams representing return air, outdoor air, and mixed air (supply air before it has been heated or cooled) are accessible for separate measurement. Some systems are already equipped with an averaging thermometer that is strung diagonally across the mixed air chamber; the temperature is read out continuously on an instrument panel. Some panels read out supply, return, outdoor, and/or mixed air temperature.

2. There is at least a several degree temperature difference between the building interior and the outdoor air.

3. Total air flow in the air handling system can be estimated either by using recent balancing reports or pitot tube measurements in ductwork. As an alternative, the supply air at each diffuser can be estimated (e.g., using a flow measuring hood), and the results can be summed to calculate total system air flow.

Temperature measurements can be made with a simple thermometer or an electronic sensor. Several measurements should be taken across each airstream and averaged.

It is generally easy to obtain a good temperature reading in the outdoor air and return airstreams. To obtain a good average temperature reading of the mixed airstream, a large number of measurements must be taken upstream of the point at which the airstream is heated or cooled. This may be difficult or impossible in some systems.

The percentage or quantity of outdoor air is calculated using thermal measurements as shown to the right.

Methodology: Carbon Dioxide Measurements

CO_2 readings can be taken at supply outlets or air handlers to estimate the percentage of outdoor air in the supply airstream. The percentage or quantity of outdoor air is calculated using CO_2 measurements as shown to the right.

Using the Results

The results of this calculation can be compared to the building design specifications, applicable building codes, or ventilation recommendations such as ASHRAE 62-1989 (see page 136 in *Appendix B*) to see whether underventilation appears to be a problem.

ESTIMATING OUTDOOR AIR QUANTITIES

Using Thermal Mass Balance

$$\textbf{Outdoor air (percent)} = \frac{T_{\text{return air}} - T_{\text{mixed air}}}{T_{\text{return air}} - T_{\text{outdoor air}}} \times 100$$

Where: T = temperature (degrees Farenheit)

Using Carbon Dioxide Measurements

$$\textbf{Outdoor air (\%)} = \frac{C_S - C_R}{C_O - C_R} \times 100$$

Where: C_S = ppm CO_2 in the supply air (if measured in a room), or
C_S = ppm of CO_2 in the mixed air (if measured at an air handler)
C_R = ppm of CO_2 in the return air
C_O = ppm of CO_2 in the outdoor air

(All these concentrations must be measured, not assumed.)

Converting Percent To CFM

$$\textbf{Outdoor air (in cfm)} = \frac{\text{Outdoor air (percent)}}{100} \times \text{total airflow (cfm)}$$

Where: cfm = cubic feet per minute

The number used for total airflow may be the air quantity supplied to a room or zone, the capacity of an air handler, or the total airflow of the HVAC system. Note: The actual amount of airflow in an air handler is often different from the quantity in design documents.

AIR CONTAMINANT CONCENTRATIONS

Volatile Organic Compounds (VOCs)

Hundreds of organic (carbon-containing) chemicals are found in indoor air at trace levels. VOCs may present an IAQ problem when individual organics or mixtures exceed normal background concentrations.

Methodology: Total Volatile Organic Compounds (TVOCs)

Several direct-reading instruments are available that provide a **low sensitivity** "total" reading for different types of organics. Such estimates are usually presented in parts per million and are calculated with the assumption that all chemicals detected are the same as the one used to calibrate the instrument. A photoionization detector is an example of a direct-reading instrument used as a screening tool for measuring TVOCs.

A laboratory analysis of a sorbent tube can provide an estimate of total solvents in the air. Although methods in this category report "total volatile organic compounds" (TVOCs) or "total hydrocarbons" (THC), analytical techniques differ in their sensitivity to the different types of organics. (For discussion of measurement devices and their sensitivity, see *Overview of Sampling Devices* on page 109.)

Using the Results

Different measurement methods are useful for different purposes, but their results should generally not be compared to each other. Direct-reading instruments do not provide sufficient sensitivity to differentiate normal from problematic mixtures of organics. However, instantaneous readouts may help to identify "hot spots," sources, and pathways. TVOCs or THC determined from sorbent tubes provide more accurate average readings, but are unable to distinguish peak exposures. A direct-reading instrument can identify peak exposures if they happen to occur during the measurement period.

Methodology: Individual Volatile Organic Compounds (VOCs)

High concentrations of individual volatile organic compounds (VOCs) may also cause IAQ problems. Individual VOCs can be measured in indoor air with a moderate degree of sensitivity (i.e., measurement in parts per million) through adaptations of existing industrial air monitoring technology. Examples of **medium sensitivity** testing devices include XAD-4 sorbent tubes (for nicotine), charcoal tubes (for solvents), and chromosorb tubes (for pesticides). After a sufficient volume of air is pumped through these tubes, they are sent to a lab for extraction and analysis by gas chromatography. Variations use a passive dosimeter (charcoal badge) to collect the sample or a portable gas chromatograph onsite for direct injection of building air. These methods may not be sensitive enough to detect many trace level organics present in building air.

High sensitivity techniques have recently become available to measure "trace organics" — VOCs in the air (i.e. measurements in parts per billion.) Sampling may involve Tenax and multiple sorbent tubes, charcoal tubes, evacuated canisters, and other technology. Analysis involves gas chromatography followed by mass spectroscopy.

Using the Results

Guidelines for public health exposure (as opposed to occupational exposure) for a few VOCs are available in the World Health Organization (WHO) Air Quality Guidelines for Europe. These guidelines address noncarcinogenic and carcinogenic effects. Occupational exposure standards exist for many other VOCs. No rule-of-thumb safety factor for applying these occupational limits to general IAQ is currently endorsed by EPA and NIOSH.

Measurement of trace organics may identify the presence of dozens to hundreds of trace VOCs whose significance is difficult to determine. It may be helpful to compare levels in complaint areas to levels in outdoor air or non-complaint areas.

Formaldehyde

Formaldehyde is a VOC that has been studied extensively. Small amounts of formaldehyde are present in most indoor environments. Itching of the eyes, nose, or throat may indicate an elevated concentration. Sampling may be helpful when relatively new suspect materials are present.

Methodology

A number of measurement methods are available. Sensitivity and sampling time are very important issues in selecting a method; however, many methods allow detection of concentrations well below 0.1 ppm (see *Using the Results* below). Measurement of short-term peaks (around a two-hour sample time) is ideal for evaluating acute irritation. Dosimeters may accurately record long-term exposure but may miss these peaks.

Two commonly used methods that are generally acceptable for IAQ screening involve impingers and sorbent tubes. Other appropriate methods are also available.

Using the Results

Various guidelines and standards are available for formaldehyde exposure. Several organizations have adopted 0.1 ppm as guidance that provides reasonable protection against irritational effects in the normal population. Hypersensitivity reactions may occur at lower levels of exposure. Worst-case conditions are created by minimum ventilation, maximum temperatures, and high source loadings.

Biological Contaminants

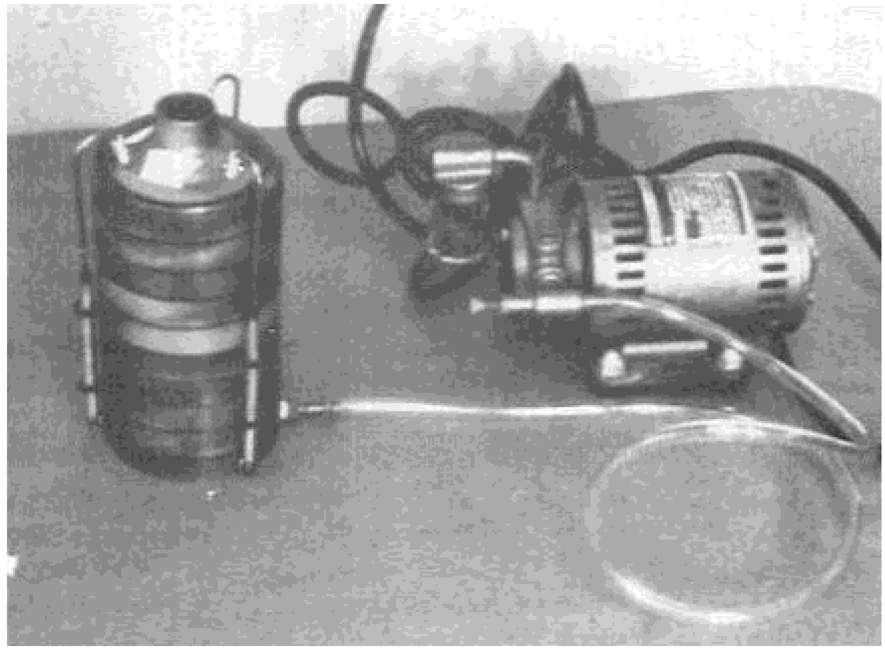
Human health can be affected by exposure to both living and non-living biological contaminants. The term “bioaerosols” describes airborne material that is or was living, such as mold and bacteria, parts of living organisms (e.g., insect body parts), and animal feces.

Testing for biological contaminants should generally be limited to:

- cases where a walkthrough investigation or human profile study suggests microbiological involvement
- cases in which no other pollutant or physical condition can account for symptoms

Methodology

Inspection of building sanitary conditions is generally preferred over sampling, because direct sampling can produce misleading results. Any sampling should be accompanied by observations of sanitary conditions and a determination as to whether any health problems appear likely to be related to biological contamination.

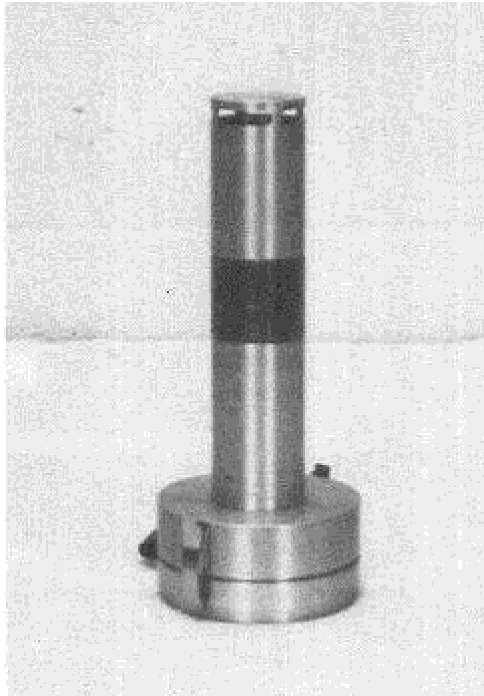


A viable impactor. Used to sample for biologicals. Training is required in order to analyze the results.

No single technique is effective for sampling the many biological contaminants found in indoor environments. A variety of specific approaches are used to retrieve, enumerate, and identify each kind of microorganism from water, surfaces, and air. Other specific methods are used for materials such as feces or insect parts. The utility of these techniques depends upon their use by professionals who have a thorough understanding of the sample site and the target organism.

Where air sampling is desired, several approaches are available. The most common type of air sampler uses a pump to pull air across a nutrient agar, which is then incubated. Any bacterial or fungal colonies that subsequently grow can be counted and identified by a qualified microbiologist. Different types of agar and incubation temperatures are used to culture different types of organisms. Only living organisms or spores in the air are counted by this method. Settling plates, which are simply opened to room air and then incubated, are sometimes used to identify which bioaerosols are present in different locations. The drawbacks to this technique are that it does not indicate the quantity of bioaerosols present and that only the

High-flow indoor particulate sampler. Used to measure particles 10 microns and smaller that are readily inhaled.



bioaerosols that are heavy enough to fall out onto the agar will be recorded.

Using the Results

Quantities and types of bioaerosols can vary greatly over time in any given building, making sampling results difficult to interpret. Comparison of relative numbers and types between indoors and outdoors or between complaint areas and background sites can help to establish trends; however, no tolerance levels or absolute guidelines have been established. Low bioaerosol results by themselves are not considered proof that a problem does not exist, for a variety of reasons:

- the sampling and identification techniques used may not be suited to the type(s) of bioaerosols that are present
- biological growth may have been inactive during the sampling period
- the analysis technique used may not reveal non-living bioaerosols (e.g., feces, animal parts) that can cause health reactions

Airborne Dust

Particles and fibers suspended in the air generally represent a harmless background but can become a nuisance or cause serious health problems under some conditions.

Methodology

A variety of collection and analytical techniques are available. Dust can be collected by using a pump to draw air through a filter. The filter can then be weighed (gravimetric analysis) or examined under a microscope. Direct readouts of airborne dust are also available (such as using meters such as those equipped with a "scattered light" detector).

Using the Results

IAQ measurements for airborne dust will be well below occupational and ambient air guidelines except under the most extreme conditions. Unusual types or elevated amounts of particles or fibers can help identify potential exposure problems.

Combustion Products

Combustion products are released by motor vehicle exhaust, tobacco smoke, and other sources, and contain airborne dust (see the previous section) along with potentially harmful gases such as carbon monoxide and nitrogen oxides.

Methodology

Direct-reading meters, detector tubes, and passive dosimeters are among the techniques most commonly used to measure carbon monoxide and nitrogen oxides.

Using the Results

Comparison with occupational standards

will reveal only whether an imminent danger exists. Any readings that are elevated above outdoor concentrations or background building levels may indicate a mixture of potentially irritating combustion products, especially if susceptible individuals are exposed.

Other Inorganic Gases

Although they are not routinely sampled in most IAQ studies, a variety of other gases may be evaluated where conditions warrant. Examples might include ammonia, ozone, and mercury.

Methodology

EPA, NIOSH, and ASTM references should be consulted for specific sampling techniques. Detector tubes or impinger methods are applicable in some cases.

Using the Results

No generalization can be applied to this diverse group of substances.