

Indoor Air Quality Handbook

A Practical Guide to Indoor
Air Quality Investigations



ENERGY AND COMFORT

Indoor Air Quality



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Indoor Air Quality Handbook

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Introduction

Concern about indoor air quality (IAQ) and the study of air quality issues is a fairly recent phenomenon. Some of the earliest documented studies occurred in Scandinavia in the mid-1960s and were focused primarily on thermal comfort issues. For the first decade or so, IAQ studies primarily involved comparing indoor air to outdoor air. The level of outdoor pollution was a chief concern and the goal was to ensure that indoor air was of better quality than the outdoor air subjected to pollutants.

As studies increased in sophistication, other measurable factors came into play. Building construction materials and techniques changed radically. A reduction in natural ventilation, or "fresh" air, in the interest of saving energy became a concern and, finally, people realized that pollutants could actually originate within a building. The World Health Organization (WHO) estimated that more than 30 percent of all commercial buildings have significant IAQ problems.



For many years, people working in areas with known exposure to potential hazards have had a number of options available with respect to personal protection, including equipment such as respirators, hard hats, gloves, goggles, and more. Indoor air quality as discussed here, however, applies to areas or situations where people are generally unaware of potential hazards. They normally do not expect to need protection and this is why the subject has become so important.



In some cases, the quality of indoor air can be critical.

Since the energy crisis of the 1970s, buildings have been constructed much tighter, significantly lowering the exchange of indoor and outdoor air. The strategy has been to save energy costs by re-circulating internal air and minimizing the need to heat, cool or condition outdoor air. Although considerable savings are realized with this strategy, unwanted contaminants can and do become trapped in these tight enclosures.

Recent developments in construction materials have resulted in the use of more synthetics and composites, which can affect air quality. Radical changes in technology have led to innovations such as computers and photocopiers that provide greater efficiencies and time savings, but they can also affect the quality of indoor air. These potentially adverse effects are further complicated by the fact that people are spending more time than ever indoors, up to 90 percent according to estimates by the U.S. Environmental Protection Agency (EPA). It is easy to understand why there is a growing concern about the quality of the air we breathe.

*People are spending more than
90 percent of their time indoors.*

As a result of these and other factors, totally new terminology has come into use and the topic is gaining more attention every day. Some examples include:

- **Sick Building Syndrome (SBS)**—where more than 30 percent of occupants experience adverse effects while in the building, but no clinically diagnosed disease is found.
- **Building Related Illness (BRI)**—general term for a medically diagnosable illness caused by, or related to, building occupancy.
- **Multiple Chemical Sensitivity (MCS) or Environmental Illness (EI)**—a controversial condition where an individual has or develops sensitivity to even low levels of certain chemicals due to extended exposure.

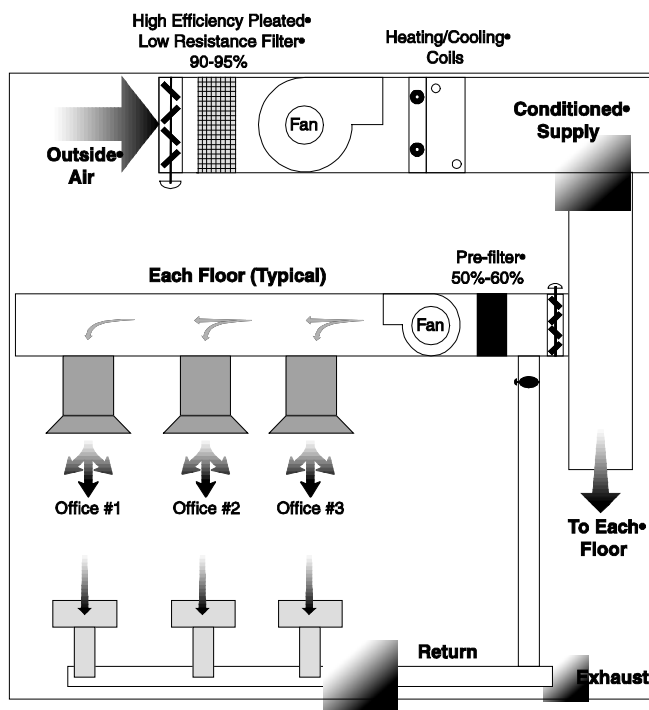
Bottom line, the quality of indoor air can and does impact productivity, personal comfort, building maintenance costs and even health and safety, either positively or negatively depending on how air quality is managed.



Building Design and Operation

Ensuring satisfactory air quality requires a good understanding of the building itself. The design, physical layout, mechanical systems, equipment and space usage are all essential elements that can affect air quality. The air distribution system requires particular attention. How does outdoor air get in? Is the air filtered? How does air circulate throughout the building?

Understand how spaces are designed and where walls, furnishings and equipment are located. Keep in mind the building layout can create physical barriers that impede the flow and distribution of air, which can impact the quality of air in a given area.

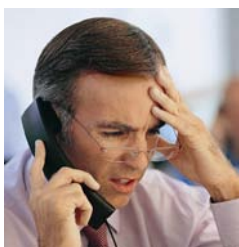


Unwanted contaminants move from areas of relative positive pressure to those of relative negative pressure through a path of least resistance.

Consider pollutant "pathways" which allow airborne gases and particles to migrate to different areas of the building. These pathways may not be obvious and are not necessarily physically defined. Pollutants can travel by air movement or pressure differential where unwanted contaminants move from areas of relative positive pressure to those of relative negative pressure through a path of least resistance.

Effects of Poor Quality Air

In this handbook, when we talk about factors affecting air quality, we are beyond the already proven hazardous materials where exposure limits have been set and personal protective equipment prescribed. Here, we address what would be considered "normal" air in offices, schools, libraries, churches, hospitals and other interior spaces where we spend time without expecting to face any risks.



Different people react differently to different levels of different substances.

As bizarre as it sounds, there is no universal reaction to a measured amount of a particular material. People simply have different tolerance levels. It is difficult to assign standards or even guidelines to set acceptable versus unacceptable levels of literally thousands of airborne pollutants.

Many indoor air contaminants are actually new, bred from the ever-changing technology that so many of us are exposed to daily. From alternative energy sources to photocopiers, we are generating new pollutants at an ever-increasing pace.

Typical symptoms caused by air quality problems vary greatly according to an individual's sensitivity and may include chills, sweating, eye irritation, allergies, coughing, sneezing, nausea, fatigue, skin irritation, breathing difficulty and others. In extreme cases, personal reactions actually reach the point where an individual cannot function, when exposed to adverse air conditions.

Unfortunately, there are virtually no Federal regulations governing exposure levels in non-industrial indoor environments. Indoor air quality is a growing concern and gaining attention. It is prudent to take a proactive approach and address any issues that could potentially have adverse affects on indoor air quality.

Types of Pollutants

General pollutant types that affect air quality include:

- **Biological**—bacteria, fungi, viruses, molds, pollen, animal hair, dander and excrement are examples of common biological pollutants that can impact air quality.
- **Chemical**—cleaners, solvents, fuels, adhesives, various combustion by-products and emissions from furnishings and floor and wall coverings are typical examples of airborne chemicals.
- **Particles and Aerosols**—are solids or liquids that are light enough to be suspended in air. Particles are classified in three general categories—coarse, fine and ultrafine—and are derived from dust, construction activities, printing, photocopying, manufacturing processes, smoking, combustion and some chemical reactions in which vapors condense to form particles. These can be categorized as dust, smoke, mist, fume and condensates.

Controlling Sources of Pollutants

In a typical building, pollutants fall into two source categories: those that enter the building from the outside and those generated within the building itself. Both include a wide variety of types and origins. Outdoor sources can include building stack exhaust, vehicle emissions, industrial processes and construction activity as well as many others. Internal sources include maintenance or housekeeping activities, chemicals, cleaners, solvents, building renovations, new furnishings, new finishes, office equipment and various occupant activities.



Pollutant sources must be located and controlled to ensure good indoor air quality. Keep in mind that both sources and pathways are essential components that must be well understood for effective problem remediation. Pathways are created as pollutants travel by air movement or from relative positive to relative negative pressure areas through even the smallest of openings. Several methods for managing a pollutant source are available once the source is identified, including:

- Removing the source
- Repairing the source so it no longer contributes pollutants
- Isolating the source with a physical barrier
- Isolating the source using air pressure differential
- Minimizing the time people are exposed
- Diluting pollutants and removing them from the building with increased ventilation
- Increasing filtration to clean the air and remove pollutants

Investigating Indoor Air Quality

A typical IAQ investigation requires several steps:

- **Planning**—
 - * Gather background information about the building and its systems.
 - * Interview affected people—understand the complaints and symptoms and check for patterns as to where and when they occur.
 - * Set objectives.
 - * Determine the strategy to be employed.
- **Gathering data**—make necessary measurements throughout the building, possibly including temperature, humidity, CO₂, CO, particles, VOCs, chemicals and bioaerosols.
- **Analyzing the data**—check for acceptable measurements to eliminate certain areas or suspected problems, as well as anomalies that direct you to areas requiring additional focus (remember, there can be multiple problems).
- **Reporting findings**—all results indicating a need for corrective action should be reported.
- **Offering assistance**—prepare an IAQ management plan that includes setting policies and conducting routine measurements to ensure good air quality is maintained.

Often, it is advisable to consult with an experienced IAQ professional, health and safety specialist or industrial hygienist when devising an IAQ investigation. So many issues must be considered in a complete investigation that this precaution will probably end up saving time and increasing the likelihood of a successful outcome.

To help steer an investigation, the affected occupants should be asked questions such as:

- 1) What symptoms are you experiencing?
- 2) When did the symptoms begin?
- 3) Are the symptoms present all the time or just during certain times (hour, day, season of the year, etc.)?
- 4) Where do the symptoms occur?
- 5) Do symptoms subside when you leave the affected the area? How soon?
- 6) Have there been changes to the area—new furniture, carpet, paint, remodeling or construction projects, etc.?
- 7) Is there a smoking or parking area nearby?
- 8) Have you recently moved?
- 9) Have you had a significant change in your activities?
- 10) Does anyone else near the affected area have symptoms similar to yours?



Measurements Used to Determine Air Quality

Several parameters must be measured and analyzed to determine the quality of indoor air and whether or not corrective action is appropriate. Remember that once a problem is discovered and corrected, an area should be routinely monitored to prevent a reoccurrence. This also helps to detect emerging problems early so they can be remedied before they become difficult and expensive to manage.

Criteria for determining indoor air quality can be separated into two basic categories—comfort and health. The difference, of course, is the way in which humans are affected, and some criteria may influence both comfort and health. Measurements associated with each of these categories are covered in the following discussion.

Comfort Issues and Productivity

Comfort is a way of measuring occupant satisfaction which, in turn, can directly affect concentration and productivity and impact the cost of doing business. Comfort is a phenomenon that is both physical and psychological, and it varies greatly from person to person. It can depend upon factors like type of clothing worn, level and type of activity and physical surroundings, including people, furnishings and adjacent spaces. Attaining optimum comfort is not practical. As a general rule of thumb, the best one can hope to achieve is satisfying about 80% of the occupants.

Comfort is a way of measuring occupant satisfaction which, in turn, can directly affect concentration and productivity and impact the cost of doing business.

Common measurable characteristics of comfort include temperature, humidity, air velocity (draft), ventilation, vibration and noise. Factors much harder to quantify yet able to impact perceived individual comfort include light glare, odors, physical space layout, proximity to other areas, clothing, activity, and ergonomics. Even emotional or psychological stress in the workplace or at home can contribute to a person's feeling of comfort.



The following discussion describes various measurements often used to determine comfort level. When making a measurement, allow sufficient time for the instrument to capture a “stable” reading. If you move from a hot area to a cold area and quickly take a temperature measurement, for example, the accuracy of the reading could be subject to question.

What to Measure—Temperature

Why measure?

Temperature is one of the basic IAQ measurements that has a direct impact on perceived comfort and, in turn, concentration and productivity. According to ASHRAE Standard 55, the recommended temperature ranges perceived as "comfortable" are 22.8 to 26.1°C (73 to 79°F) in the summer and 20.0 to 23.6°C (68 to 74.5°F) in the winter.

How to measure?

Measurements should be taken periodically at many areas of the building to be sure that air is distributed evenly and temperatures are consistent. TSI offers a number of instruments that measure temperature. These include IAQ monitors, thermohygrometers and multi-parameter ventilation meters.

What to Measure—Humidity

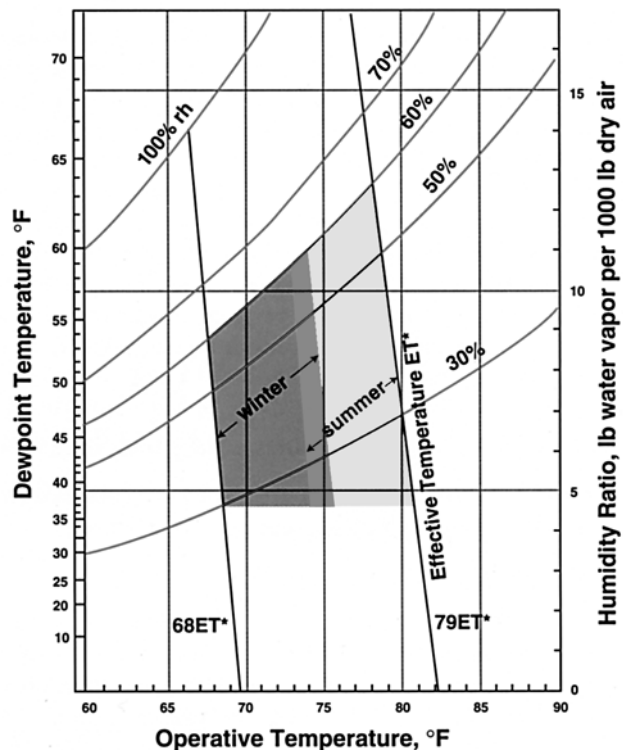
Why measure?

Too little humidity in a space may create static build-up and people will sense that their skin feels dry. Too much humidity and people will think it feels "sticky." According to ASHRAE Standard 55, indoor humidity levels should be maintained between 30 percent and 65 percent for optimum comfort.

How to measure?

Humidity can be measured in several ways. Typically, references such as relative humidity, wet bulb, dry bulb, humidity ratio and absolute humidity are used. Whichever method is chosen, measurements should be taken periodically and spread throughout the building to ensure that air is distributed evenly and humidity levels are consistent and within goals. As with temperature, TSI offers several portable instruments that measure humidity, including IAQ monitors, thermohygrometers and multi-parameter ventilation meters.

ASHRAE Standard 55 links temperature and humidity together to provide a measure of thermal comfort. The objective should be to set the appropriate temperature and humidity levels so as to maximize occupant comfort while controlling energy consumption. The "comfort zone" shown on the graph is based on the subjective response of people tested under a variety of conditions and their perception of what was or was not comfortable. Compare the actual temperature and humidity data collected to the graph to determine if an area is within the prescribed comfort zone.



What to Measure—Air Movement and Flow
The three V's—Velocity, Volume and Ventilation

Velocity—
Why measure?

One of the first checks, often overlooked, in a comfort study is making sure that sufficient air is moving in a space. Air movement can affect human comfort level in that too much is perceived as “drafty” or “chilly” and too little may create a sensation of stuffiness.

How to measure?



A quick spot check at the supply diffuser will show if sufficient air is entering a space. This will assure there are no unexpected blockages in the air system, such as a closed damper. Velocity is also a good indicator that air is being appropriately distributed or balanced throughout the building and reaching all the spaces intended. Measurements should also be taken in the actual occupied “zones” to assess how air velocity affects individuals. TSI provides several instruments for making quantitative air velocity measurements, including air velocity meters, rotating vane anemometers and the multi-parameter ventilation meters.

Volume—
Why measure?

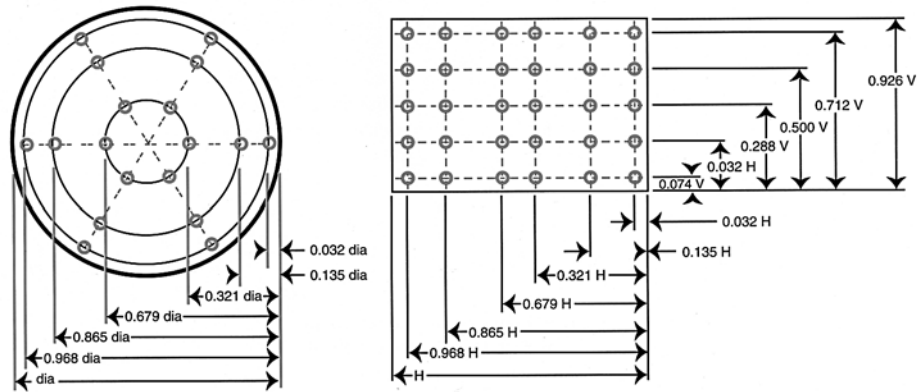
ASHRAE Standard 62 lists recommended outdoor air requirements expressed in terms of cubic feet per minute (cfm) per person depending on the type of space and activity. The Percent Outdoor Air must be calculated (see ventilation section). This percentage can then be multiplied by the measured airflow to calculate the amount of outdoor air being supplied. Air volume or flow into an area affects the air change rates or exchange of air between outdoors and indoors. This results from leakage and natural or mechanical ventilation systems. The exchange of air can have a large impact on indoor air quality as it may increase the amount of outdoor pollutants being introduced or, conversely, dilute and help remove contaminants generated indoor.

How to measure?

Air velocity is seldom uniform across any section of an air duct. The shape of a duct, its turns and branches and friction all affect the movement of air. In general, air tends to move slower toward the edges or corners and faster in the center of a duct. The average air velocity can be determined using a straight average for both round and rectangular ducts using the log-Tchebycheff method, a method that accounts for velocity losses due to friction. As the figure below indicates, velocity measurements should be taken at a minimum of 25 points for rectangular ducts and, for round ducts, symmetrically disposed diameters with at least 6 points on each should be used.

For the greatest accuracy, take these measurements at least 7.5 diameters downstream or 3 diameters upstream from any disturbance such as an elbow, venturi or take-off. ASHRAE Standard 111 has additional details on measuring flow in ducts.





Location of measuring points for traversing round or rectangular ducts using the log-Tchebycheff method

To determine volumetric flow rate, the average measured air velocity is multiplied by the cross-sectional area of a duct. For example, if a duct is 2 feet by 2 feet (cross-sectional area = 4 square feet) and the average measured air velocity is 150 feet per minute, the resulting flow rate is 150 ft/min x 4 square feet or 600 cfm (cubic feet per minute). Multi-parameter ventilation meters are capable of calculating automatically the volumetric flow rate when the cross-sectional area of a duct is entered.

An air capture hood can also be used to determine air flow. Capture hoods provide quick, direct measurements of air flow from diffusers, vents or grilles. They are capable of collecting and storing real-time flow measurements and they are also valuable when balancing the system for proper flow in all areas.

Air velocity meters, multi-parameter ventilation meters and air capture hoods all provide a fast, accurate means for measuring volumetric airflow.

***Ventilation—
Why measure?***

The introduction of outdoor air helps dilute unwanted pollutants and gets them out of the building faster. ASHRAE Standard 62 presents recommendations pertaining to ventilation, or the amount of outdoor air introduced into a given area. It recommends a minimum volume per person over time, depending on the type of space and activity being performed, expressed in cubic feet per minute per person.

How to measure?

A good indicator of proper ventilation is the level of CO₂ present in a space. Carbon dioxide is a normal by-product of respiration, combustion and other processes. Elevated levels of CO₂ may indicate that additional ventilation is required. ASHRAE Standard 62 recommends an indoor level not to exceed about 700 ppm above outdoor ambient air which is typically about 300 to 400 ppm. Under normal conditions, even elevated CO₂ levels are rarely a health hazard since levels up to 10,000 parts per million can be tolerated without ill effects by healthy people.



Measurements should be taken between different areas, in air distribution zones, at varying heights and between indoor and outdoor areas to ensure that the building is properly ventilated.

The amount of outdoor air entering the building can be calculated as a percentage of the total air volume. This calculation can be done using either temperature or CO₂. Three measurements need to be taken: return air, supply air and outdoor air. The equation is as follows:

$$\text{Percent Outdoor Air} = \frac{\text{RAM} - \text{SAM}}{\text{RAM} - \text{OAM}} \times 100$$

Where: RAM = Return Air Measure
 SAM = Supply Air Measure
 OAM = Outdoor Air Measure

IAQ monitors can be used to measure both temperature and CO₂ simultaneously and perform this percent outdoor air calculation automatically when the three measurements are entered. Many monitors are also equipped with data logging capability so that an area can be monitored over time to see if action needs to be taken to change ventilation amounts or patterns.

When the volumetric flow rate (cfm) is determined, the amount of outdoor air (OA) entering the space can be calculated by multiplying the flow rate by the percent outdoor air (see volume section).

$$\text{Air flow (cfm)} \times \% \text{OA} = \text{OA\% cfm}$$

The next step is calculating the volume of outdoor air per person.

$$\text{OA\% cfm} \div \text{no. of people} = \text{volume of OA per person (in cfm)}$$

This calculation can then be compared to the table in ASHRAE Standard 62 to determine if an adequate amount of outdoor air per person is being supplied for a particular type of space. The following table lists a few examples taken from Table 2 in the standard.

Application	cfm/person (outdoor air)
Dining areas	20
Kitchens	15
Hotel/motel rooms	15
Parking garages	1.5 cfm/ft ²
Office space	20
Conference rooms	20
Public rest rooms	50
Smoking areas	60
Retail stores (typical)	15
Gymnasium	20
School classroom	15
School laboratories	20
Auditoriums/theaters	15
Libraries	15
Patient rooms	25
Health procedure & recovery rooms	15
Operating rooms	30
Residential living areas	15
Residential kitchens	25
Residential bath	20
Residential garage	100 cfm/vehicle

Approved in 2004, Addendum 62n to ASHRAE Standard 62 incorporates a number of new variables and equations for determining more effective dilution and evacuation of pollutants generated by the building and its occupants. The International Mechanical Code and other organizations that govern design, construction, commissioning and inspection of buildings have yet to adopt this new standard, and the addendum remains a guideline.

Health and Safety Issues

While comfort is important in maintaining productivity and concentration, many unwanted airborne contaminants can actually pose a threat to human health. Unhealthy IAQ conditions occur whenever vapors, gases or airborne particulates are present in concentrations that adversely affect one or more occupants of a space.

Potentially toxic, infectious, allergenic, irritating or otherwise harmful substances are almost always around us. Usually they exist in such small concentrations that stay below a “trigger” threshold and get little attention. When concentrations rise above the threshold, problems can begin. Even at relatively low concentrations, some individuals are very sensitive to certain substances and may react adversely even though other area occupants are not bothered. In very extreme cases, concentrations may be high enough to be fatal to all occupants. Dangerous airborne substances are serious matters and must be dealt with, proactively, before problems get out of control.

What to Measure—Carbon Monoxide

Why measure?

Carbon monoxide (CO) is a colorless, odorless, poisonous gas that is a by-product of incomplete combustion. When inhaled, it readily mixes with hemoglobin in the blood, inhibiting the blood's ability to carry and exchange oxygen. Carbon monoxide does not readily leave the body once it enters and treatment in some cases may even require a blood transfusion. Excessive exposure to carbon monoxide can starve the body of oxygen and lead to death. Even a few parts per million is reason to immediately investigate this serious health concern.

The U. S. EPA has set National Primary Ambient Air Quality Standards for Outdoor Air to be used in locating ventilation sources for buildings. Exposure limits for CO are an average of 35 ppm for one hour, not more than one time per year, or 9 ppm over any eight-hour period. The American Conference of Government Industrial Hygienists (ACGIH) and U.S. Occupational Safety and Health Administration (OSHA) have also set maximum exposure limits in the Industrial Workplace Standard. There are no Federal regulations governing carbon monoxide exposure limits in non-industrial indoor environments.



How to measure?

Measurements of carbon monoxide should be taken periodically and spread throughout many areas in a building to be sure that air is being distributed evenly and no dangerous levels of CO are detected. Pay particular attention to areas in which any form of combustion takes place. Typical examples of outdoor CO sources in a building include vehicular emissions from traffic or parking areas and building exhaust stacks. Indoor sources include furnaces, boilers, stoves and smoking areas. Instruments that measure carbon monoxide in real time include the IAQ monitors and combustion analyzers.

What to Measure—Airborne Particles

Why measure?

Respiration of particles challenges the body's natural defense mechanisms and overexposure may strain these mechanisms, causing an adverse reaction. Inhalable particles are typically defined as those with an aerodynamic diameter of 10 micrometers or smaller, commonly referred to as PM10. Respirable particles, or those that readily enter the lungs, are usually classified as less than 4 microns in diameter. Sources may include dust, mists, fumes, smoke, environmental tobacco smoke (ETS) and other particulate by-products of combustion. ASHRAE Standard 62 recommends a maximum exposure limit for PM10 particles of 0.15 mg/m³ for a 24-hour average and 0.05 mg/m³ for an annual average exposure. This is consistent with the EPA's National Ambient Air Quality Standards. The industry is moving in the direction of concern for smaller particles since they bypass natural defense mechanisms more readily and make their way deep into the lungs.

Respiration of particles challenges the body's natural defense mechanisms and overexposure may strain these mechanisms causing an adverse reaction.

How to measure?

First, it is important to minimize airborne particles as much as possible using more routine means such as good housekeeping practices, upgrading filters, maintaining a positive pressure relative to the outdoors and having proper exhaust design. Even with these practices in place, airborne particles may enter workspaces.



When it does become necessary to measure airborne particles, two basic methods typically are used: air sampling over time and measurements employing real-time instruments. With air sampling over time, materials are most often collected on a filter medium and subsequently analyzed in an environmental laboratory located away from the sampling location. With real-time instruments, measurements are made and results obtained on-site.

Three types of instruments—photometers, optical particle counters and condensation particle counters—normally are used for real-time measurements. Performance features and applications for the three are compared in the following charts. The specific instrument of choice depends on the application and the desired results.

Features	Photometer	OPC	CPC
Typical Size Range	0.1 to 10 µm	0.3 to 20 µm	0.02 to 1.0 µm
Measures Particle Mass	Yes	No	No
Measures Particle Size	No	Yes	No
Detects Single Particles	No	Yes	Yes
Typical Mass Concentration Range	0.01 to 100 mg/m ³	N/A	N/A
Typical Number Concentration, Upper Limit	N/A	2 x 10 ⁶ Particles/ft ³ 70 Particles/cm ³	1.5 x 10 ¹⁰ Particles/ft ³ 500,000 Particles/cm ³

Applications	Photometer	OPC	CPC
Indoor Air Quality – Conventional studies	Good	Good	Excellent
Indoor Air Quality – Ultrafine particle tracking	Poor	N/A	Excellent
Industrial Workplace Monitoring	Excellent	Poor	Excellent ¹
Outdoor Environmental Monitoring	Good	Good	Excellent ¹
Emissions Monitoring	Excellent	Poor	Good
Respirator Fit Testing	Excellent	Poor	Excellent
Filter Testing	Excellent	Excellent	Excellent
Clean Room Monitoring	Poor	Excellent	Excellent

¹Health effects of ultrafine particles (below 0.1 µm) are not completely understood, though research suggests that they may cause the greatest harm. There are currently no established exposure limits or governmental regulations specifically addressing ultrafines.

Most guidelines offered by ASHRAE and the EPA are written in terms of mass concentration per volume rather than absolute counts. TSI's product offering in this area includes an aerosol monitor, which is a photometer that measures particle mass per volume in real-time for particles ranging from 0.1 to 10 micrometers diameter.

What to Measure—Ultrafine Particles

Why measure?

Ultrafine particles (UFPs), defined as particles less than 0.1 micrometer diameter, are often produced by combustion and some chemical reactions. They are so small that they can pass easily through the body's natural defense mechanisms to the deepest areas of the lungs. Certain people are extremely sensitive to ultrafine particles, sometimes regardless of chemical composition. It is suspected that the sheer number of particles and their cumulative surface area may trigger a reaction in these people.

As of this writing, no specific guidelines or standards have been developed for ultrafine particles. Much research currently is being done, however, and some initial results have linked UFPs to potentially adverse health conditions. There are thousands of case studies where indoor air quality was suspected as the reason for health complaints and, when a source of UFPs was located and controlled, the complaints went away. Often, this happened after conventional IAQ measurements had failed to identify any serious problems that would likely be the cause.



These very tiny particles migrate on “pathways” driven by air movement or differences in air pressure. Because of their extremely low mass, they can take days, weeks or even months to settle out of the air. Ultrafine particles can penetrate even the smallest opening and are not detectable using most conventional particle detection instruments.

How to measure?

The only practical instrument for detecting ultrafine particles is a condensation particle counter (CPC), a device that “grows” the small particles to a size large enough to be counted using conventional particle counting techniques. TSI's ultrafine particle counter employs CPC technology to detect and track ultrafine particles within the building environment.

The method for tracking UFPs begins outdoors where several measurements are made with the particle counter to establish a baseline. If the building's intake air is filtered, you can subtract from the base-line measurement a percentage of particulates roughly equal to the efficiency rating of the filter to establish an indoor goal. For example, a 75% efficient filter effectively removes about three-quarters of all particles leaving 25% of the outdoor reading as the goal. Inside, measurements are taken and compared to this indoor goal. Seek levels of ultrafine particles greater than the goal to find sources of particles that might contribute to air quality problems. A basic understanding of the ventilation system and how outdoor air is introduced, filtered and distributed throughout the building is necessary for an effective investigation.

If levels of ultrafine particles significantly higher than expected are found anywhere in the building, take steps to locate and identify the source. Using the particle counter much like a Geiger counter, ultrafines can be traced quickly and easily directly to their source. Once a source is located, remedial action to control, repair or remove it is often straightforward.

Remember that in a thorough investigation there may be, and often are, multiple problems or sources of UFPs. Unmasking and solving one source of particles allows you to search out the next. Continue until no additional sources are found. Routine, ongoing monitoring helps ensure that problems do not resurface, and new issues can be dealt with quickly before they become serious or expensive to correct.

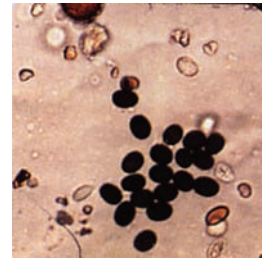
Studies have shown elusive ultrafine particles may lead to problems even though other parameters are within acceptable levels.

Another important parameter to consider along with ultrafine particles is differential air pressure. Airborne particles travel along seen and unseen pathways and are driven by air movement and pressure differential. Small particles naturally migrate from areas of higher to lower relative pressure. Even very small differences cause movement. TSI's micromanometers offer a means for accurately measuring differential pressure to help identify these pathways.

What to Measure—Bioaerosols

Why measure?

Bioaerosols are defined by the ACGIH as airborne particles, large molecules or volatile compounds that are living or were released from a living organism. Types of most concern for IAQ and included in this definition are plants, including fungi, yeasts, molds, mildews and pollen, as well as bacteria, endotoxins, viruses, antigens, and animal parts. Bioaerosols range in size from less than 0.1 micrometer to 100 micrometers in diameter.



Some of these bioaerosols contain dangerous toxins that in extreme cases can cause a range of adverse health effects, including death. Mechanisms may include immunologic hypersensitivity, infection and toxic reaction. Diseases typically associated with bioaerosol dispersion include Legionellosis, Pneumonia, Tuberculosis, Histoplasmosis, Aspergillosis, asthma, cancer and others. Generally, most healthy people are able to fend off adverse effects from exposure.

Besides serious diseases, some bioaerosols can also cause varying levels of irritation in certain individuals, including allergic reactions, headaches, eye irritation, sneezing, fatigue, nausea, difficult breathing and more. About 10 percent of the population is allergic to one or more of the hundreds of thousands of different types of mold alone. As with other particles, bioaerosols may irritate certain sensitive individuals regardless of the bioaerosol composition or level of toxicity.

How to measure?

Most biological growth requires some kind of food and water. Condensation, plumbing leaks, roof leaks, or even improper housekeeping can lead to unwanted moisture which can foster unwanted growth that must be checked and corrected. At this time, bioaerosols such as molds, fungi and bacteria must be collected, cultured and analyzed in an environmental microbiology laboratory setting to determine exactly what they are and how large of a presence they have. Sampling often consists of collecting material through an air sample on different sized filter media. In commercial and residential environments, "settle plates" and surface swabbing are not viable means of testing for biologicals. These methods were developed for testing in highly controlled environments and may grossly understate or overstate the condition in commercial and residential environments. The analysis portion of the testing may take days or even weeks before results are determined. While there are some large, expensive research-grade instruments that can be used to assess biological material, there are no practical, portable "real-time" instruments that reliably measure biologicals.

What to Measure—Chemicals in Aerosol Form (Condensates)

Why measure?



A wide variety of chemicals in gas, vapor or particle form can become airborne and have potentially adverse health effects in certain individuals. In cases where exposures are known, personal protective equipment is available to control contact. It is the unexpected exposure in areas where risk is not normally assumed that causes concern.

Some common chemicals of special concern include, but are not limited to, lead, radon, formaldehyde, environmental tobacco smoke and volatile organic compounds (VOCs). VOCs are a broad class of chemicals containing carbon atoms that tend to give off high levels of vapor even at room temperature. They typically are found in building materials, cleaners, solvents, paints, gasoline and other substances.

Airborne chemicals—particles, vapors or gases—can originate from sources within a building or enter it by several means. They enter the building on air currents or by seeking relatively negative pressure areas. Chemicals in the soil can be tracked in and become airborne. And, finally, the deterioration or disturbance of materials containing unwanted chemical compounds can introduce airborne particles. For many of the materials that fall into this category, there do exist established exposure levels for chemicals known to be dangerous that are set by EPA (National Ambient Air Quality Standards) or OSHA regulations that apply in the industrial workplace.

How to measure?

Some of the tools available include electrochemical and infrared (NDIR) gas sensors designed to identify particular gases present in industrial settings, from combustions, emissions and other situations that could impact air quality. Photo-ionization and flame-ionization detectors can be used to identify many VOCs that can impact IAQ.

In most cases, it is difficult to get an accurate picture of the extent of chemical contaminants in the air using real-time data collection. It is more often a complex mix rather than individual compounds that pose the difficult challenge. Consequently, sampling is an accepted practice generally conducted using techniques such as filtration, absorption in another media, or impaction.

What to Measure—Light, Noise, Vibration, Ergonomics, Odors, etc.

Why measure?

It is important here to recognize that a healthy, productive working or living environment consists of more than just good quality air. The entire picture must be considered in order to optimize occupant

The entire picture must be considered in order to optimize people's satisfaction and productivity.

satisfaction and productivity. There are guidelines and standards that pertain to other factors that contribute to the total working environment, and instrumentation is available that objectively measures some of these parameters in real time. Further details are outside the scope of this book.

Conclusion

While investigating any indoor air quality situation, be aware of the entire picture. Many parameters that may be contributing to an overall problem must be considered and checked. Also keep in mind that it is not uncommon to find multi-layered problems, and finding and solving one issue may not get to the root cause. Think of an investigation as peeling an onion; as each layer is removed, another is exposed.

Be sure to understand the exact time and place that problems are suspected, since many IAQ problems come and go in a moment. Use common sense along with the proper tools and keep investigating and correcting problems until complaints stop.

Sources for Information Relating to Indoor Air Quality Evaluations

The following is a partial list of organizations offering information on indoor air quality:

Aerias, LLC—www.aerias.org
Air Conditioning Contractors of America (ACCA)—www.acca.org
Air Conditioning and Refrigeration Institute (ARI)—www.ari.org
Air Diffusion Council (ADC)—www.flexibleduct.org
American Board of Industrial Hygienists (ABIH)—www.abih.org
American Conference of Governmental Industrial Hygienists (ACGIH)—www.acgih.org
American Indoor Air Quality Council (AmIAQ)—www.iaqcouncil.org
American Industrial Hygiene Association (AIHA)—www.aiha.org
American Lung Association (ALA)—www.lungusa.org
American National Standards Institute (ANSI)—www.ansi.org
American Society for Testing and Materials (ASTM)—www.astm.org
American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)— www.ashrae.org
ASHRAE Fundamentals Handbook—www.ashrae.org
ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy
ASHRAE Standard 62, Ventilation for Acceptable Air Quality
ASHRAE Standard 111, Practices for Measuring, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems
American Society of Safety Engineers (ASSE)—www.asse.org
Asthma and Allergy Foundation of America (AAFA)—www.aafa.org
Building Air Quality Alliance
Building Owners and Managers Association (BOMA)—www.boma.org
Center for Disease Control and Prevention (CDC)—www.cdc.gov
Government Information Exchange
Healthy Buildings International (HBI)—www.hbi.com.au
Indoor Air Quality Association (IAQA)—www.iaqa.org
International Facility Management Association (IFMA)—www.ifma.org
National Air Duct Cleaners Association (NADCA)—www.nadca.com
National Air Filtration Association (NAFA)—www.nafahq.org
National Institute for Occupational Safety and Health (NIOSH)—www.cdc.gov/niosh/homepage.html
National Institute of Standards and Technology (NIST)—www.nist.gov
National Institutes of Health (NIH)—www.nih.gov
National Safety Council (NSC)—www.nsc.org
U.S. Department of Health and Human Services (HHS)—www.hhs.gov
U.S. Department of Labor Occupational Health and Safety Administration (OSHA)—www.osha.gov
U.S. Environmental Protection Agency (EPA)—www.epa.gov
U.S. Public Health Service (PHS)—www.hhs.gov/phs

A host of trade publications, books and web sites dedicated to IAQ issues also are excellent sources of information but are far too numerous to mention here.

Standards and Guidelines

Parameter	Limit/Range		Reference	TSI Instrument
Temperature	Summer 73 to 79°F Winter 68 to 74.5°F		ASHRAE Standard 55-1992 ISO 7730	Q-TRAK IAQ-CALC TH-CALC VELOCICALC
Relative Humidity	30% to 65%		ASHRAE Standard 55-1992 ISO 7730	Q-TRAK IAQ-CALC VELOCICALC TH-CALC
Air Movement	0.8 ft/s or 0.25 m/s		WHO ISO 7730	VELOCICALC DP-CALC ACCUBALANCE
Ventilation (outdoor air)	Recommended volume/person minimum depending on type of space and activity		ASHRAE Standard 62-2003 (Table 2)	Q-TRAK IAQ-CALC TH-CALC
Ventilation (CO ₂)	No more than about 700 ppm over outdoor ambient		ASHRAE Standard 62-2003	Q-TRAK IAQ-CALC
Ultrafine Particles <1.0 micron	n.a.		n.a.	P-TRAK
	8 hr. TWA	1 hr. TWA		
Carbon Monoxide	50 ppm 35 ppm 9 ppm 9 ppm (peak) 25 ppm 9 ppm	– – 35 ppm – – 26 ppm	OSHA NIOSH EPA ASHRAE ACGIH WHO	Q-TRAK IAQ-CALC CA-CALC

IAQ Instruments from TSI



Q-TRAK™

Indoor Air Quality Monitors

Model 7575

- Measures CO₂, CO, temperature and humidity simultaneously
- Calculates dew point, wet bulb and percent outside air
- Large graphic display
 - Displays up to five measurements
 - On-screen messages and instructions
 - Supports 12 different languages
- One instrument with multiple plug-in probe options including VOC's and air velocity
- Stores up to 39 days of data collected at one-minute log intervals
- TRAKPRO™ data analysis software provided for data logging, analysis and documenting results
- Bluetooth communications for transferring data or remote polling



IAQ CALC™

Indoor Air Quality Meters

Models 7515, 7525, 7535, 7545

- Fast and accurate CO₂, temperature, humidity and CO readings
- % outside air calculations
- Statistics including average, maximum, and minimum values
- Downloads to spreadsheet or database using LogDat2™ software (7525, 7535, 7545)

IAQ Monitor Feature Chart

Model	Feature				
	CO ₂	CO	Temp	RH	Datalog
7515	•				
7525	•		•	•	•
7535	•				•
7545	•	•	•	•	•
7575	•	•	•	•	•



Volatile Organic Compounds (VOC)

Indoor Air Quality Probes

Models 984, 985, 986, 987

- Pre-calibrated plug-and-play accessory probes for TSI Model 7575 Q-TRAK™ monitor
- Compact design with ergonomic handle
- Four versions available with multiple measurement capability
 - Model 984 - Low concentration (ppb) VOC and temperature
 - Model 985 - High concentration (ppm) VOC and temperature
 - Model 986 - Low concentration (ppb) VOC, temperature, CO₂ and humidity
 - Model 987 - High concentration (ppm) VOC, temperature CO₂ and humidity
- Calculates VOC exposure in mass concentration
 - Requires knowledge of VOC being measured
 - Enter specific response factor into meter
- Two-year factory warranty
- Send only the probe back for factory calibration



VELOCICALC®

Air Velocity Meters

Models 9535, 9535-A, 9545, 9545-A

- Wide air velocity range of 0 to 6,000 ft/min (0 to 30 m/s)
- Easy recording of multiple measuring points
- Calculates valuable statistics—average, maximum and minimum values, and records the number of samples
- Flow rate calculated automatically
- Durable telescoping probe with etched length marks
- Humidity measurement [Models 9545 and 9545-A]



ACCUBALANCE®

Air Capture Hood

Model 8375

- Ergonomic design and ultra light weight for easy one person operation
- Detachable digital manometer for use in other applications with Pitot, air flow, temperature, velocity matrix, or relative humidity probes
- Back pressure compensated
- Multiple hood sizes available
- Bio-Safety hood kit available



DP-CALC™

Micromanometers

Models 5815, 5825, 8710

- Accurately measures differential and static pressure
- Wide measurement range of -15 to +15 in. H₂O (-3735 to 3735 Pa)
- Automatic conversion of actual and standard flows (Model 5825, 8710)
- Flowrate automatically calculated (Model 5825, 8710)
- Measures velocity with Pitot tube in high temperature and contaminated areas
- Auto-zeroing technology (8710)



SIDEPAK™

Personal Aerosol Monitors (Photometer)

Model AM510

- Measure aerosol mass concentrations in real time
- Small, lightweight and quiet
- PM₁₀, PM_{2.5}, PM_{1.0} and respirable fractions
- Belt mounted
- Battery operated
- Data logs and downloads to a PC for analysis and reporting



DUSTTRAK™ II and DRX

Aerosol Monitors

Models 8530, 8532, 8533 and 8534

- Measures mass in high concentrations up to 400 mg/m³ (Model 8530, 8532)
- Simultaneously measure size-segregated mass fraction concentrations corresponding to PM₁, PM_{2.5}, Respirable, PM₁₀, and Total PM size fractions (Model 8533, 8534)
- Easy to program, easy to operate
- New graphical user interface with color touch-screen
- Perform in-line gravimetric analysis for custom reference calibrations
- Automatic zeroing (with optional zero module) minimizes the effect of zero drift
- Measure aerosol concentrations corresponding to PM₁, PM_{2.5}, PM₁₀, or Respirable size fractions



P-TRAK™

Ultrafine Particle Counters (CPC)

Model 8525

- Counts ultrafine particles less than 1 micron diameter in real-time
- Tracks to the source
- Portable, battery operated
- Data logs to document results



AERO TRAK™

Handheld Particle Counter

Model 9306

- Complies with all requirements of ISO 21501-4
- 0.3 to 25 μm size range
- 0.1 CFM (2.83 L/min) flow rate
- Measures up to six channels of simultaneous data
- Model 9306-V2 provides unique variable binning option
- Integrated handle for one hand operation
- Removable, rechargeable Li-ion battery
- Long life laser diode
- USB and Ethernet output
- 10,000 sample record storage, 250 locations
- Local or remote configuration via web browser
- Provides Pass/Fail reporting on ISO 14644-1, EU GMP, and FS209E
- Compatible with TRAKPRO™ Lite and FMS 5 software packages
- Optional Temperature/RH sensor available

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