



® Knowledge
Beyond
Measure.

Indoor Air Quality Handbook

A Practical Guide to
Indoor Air Quality Investigations



Contents

Introduction	1
Building Design and Operation	3
Effects of Poor-Quality Air.....	3
Types of Pollutants.....	4
Controlling Sources of Pollutants.....	4
Investigating Indoor Air Quality	5
Measurements Used to Determine Air Quality	6
Comfort Issues and Productivity	6
What to Measure—Temperature	7
What to Measure—Humidity	7
What to Measure—Air Movement and Flow The three V's—Velocity, Volume and Ventilation.....	8
Health and Safety Issues	11
What to Measure—Carbon Monoxide	11
What to Measure—Airborne Particles	12
What to Measure—Ultrafine Particles.....	13
What to Measure—Bioaerosols	14
What to Measure—Chemicals in Aerosol Form (Condensates).....	15
What to Measure—Light, Noise, Vibration, Ergonomics, Odors, etc.....	15
Conclusion.....	16
Sources for Information Relating to Indoor Air Quality Evaluations	17
Standards and Guidelines	18
Indoor Air Quality Instruments from TSI® Incorporated	19

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.

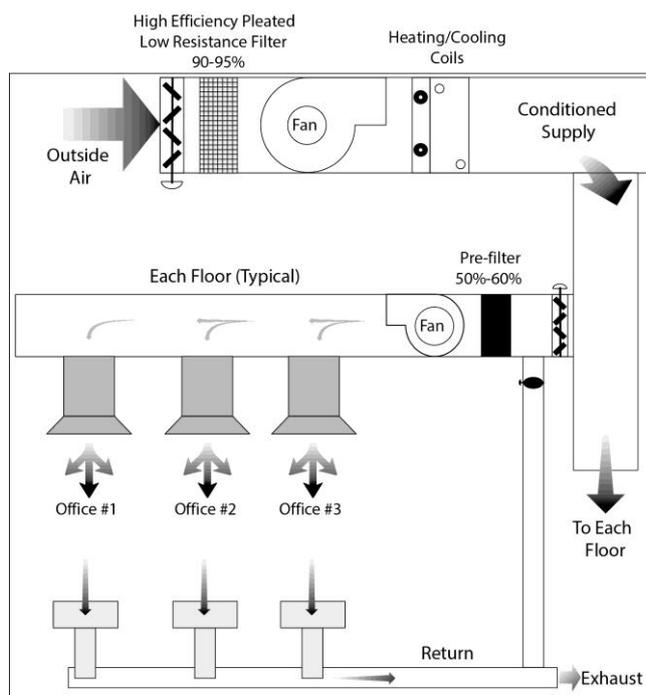


Building Design and Operation

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.

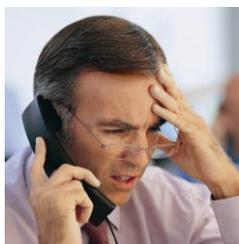
Unwanted contaminants move from areas of relative positive pressure to those of relative negative pressure through a path of least resistance.



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 effects 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 75 to 80°F (24 to 27°C) in the summer and 68 to 75°F (20.0 to 24°C) 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

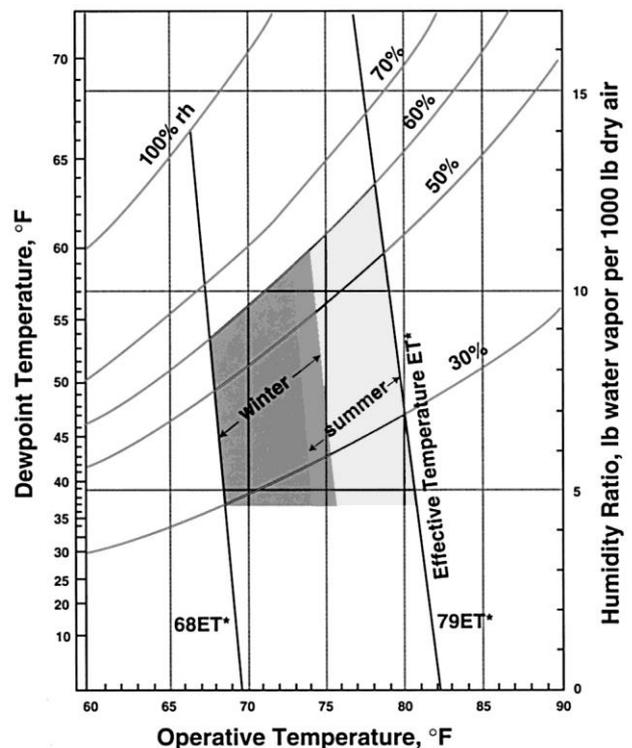
Why measure?

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 60 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?

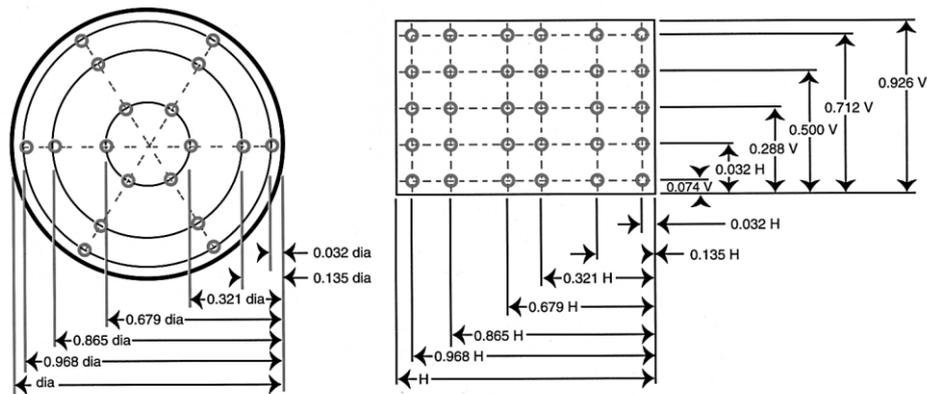
ASHRAE Standard 62 lists recommended outdoor air requirements expressed in terms of cubic feet per minute (cfm) per person depending on the type of space and activity. The Percent Outdoor Air must be calculated (see ventilation section). This percentage can then be multiplied by the measured airflow 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:

$$\% \text{ outside air} = \frac{\text{return air measurement}^* - \text{supply air measurement}^*}{\text{return air measurement}^* - \text{outside air measurement}^*} \times 100$$

* measurement refers to either CO₂ or temperature

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 62.1 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 6-1 in the standard.

Application	ft ³ /min per person (outdoor air)	L/s per person (outdoor air)
Auditorium seating area	5	2.5
Computer lab	10	5
Music/theater/dance	10	5
Wood/metal shop	10	5
Cafeteria/fast food dining	7.5	3.8
Hotel rooms	5	2.5
Hotel lobbies	7.5	3.8
Courtrooms	5	2.5
Main entry lobbies	5	2.5
Museums	7.5	3.8
Office space	5	2.5
Mall common areas	7.5	3.8
Gym, sports arena	20	10
School classroom	10	5
Science laboratories	10	5

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?

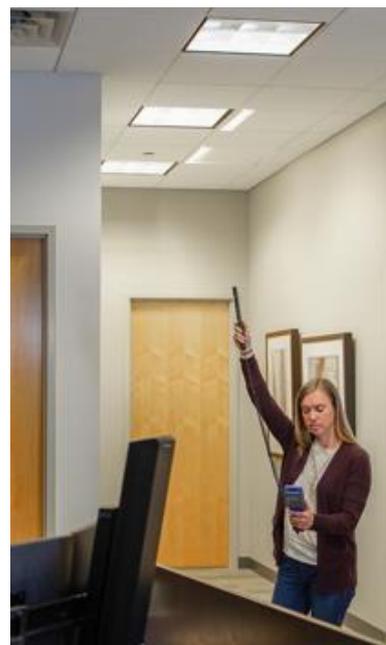
Carbon monoxide (CO) is a colorless, odorless, poisonous gas that is a by-product of incomplete combustion. When inhaled, it readily mixes with hemoglobin in the blood, inhibiting the blood's ability to carry and exchange oxygen.

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?

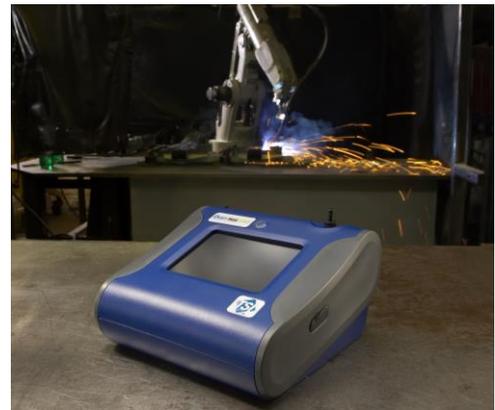
Respiration of particles challenges the body's natural defense mechanisms and overexposure may strain these mechanisms, causing an adverse reaction. Inhalable particles are typically defined as those with an aerodynamic diameter of 10 micrometers or smaller, commonly referred to as PM10. Respirable particles, 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.

	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

	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

Health 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[®] Incorporated'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.

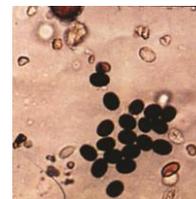
Studies have shown elusive ultrafine particles may lead to problems even though other parameters are within acceptable levels.

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® Incorporated'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 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.

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

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:

Air Conditioning Contractors of America (ACCA) – www.acca.org
Air Conditioning and Refrigeration Institute (ARI) – <http://www.lightindustries.com/ARI/>
Air Diffusion Council (ADC) – www.flexibleduct.org
American Board of Industrial Hygienists (ABIH)—<http://www.abih.org>
American Conference of Governmental Industrial Hygienists (ACGIH)—<http://www.acgih.org>
American Council for Accredited Certification (ACAC) – <http://www.acac.org>
American Industrial Hygiene Association (AIHA) – www.aiha.org
American National Standards Institute (ANSI) – www.ansi.org
American Society for Testing and Materials (ASTM) – www.astm.org
ASHRAE Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) – www.ashrae.org
ASHRAE Fundamentals Handbook—<http://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)—<http://www.aafa.org>
Building Air Quality Alliance (BAQA)
Building Owners and Managers Association (BOMA)—<http://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 Dust 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 Institute of Health (NIH) – www.nih.gov
National Safety Council (NSC)—<http://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

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 75 to 80°F (24 to 27°C) Winter 68 to 75°F (20 to 24°C)		ASHRAE Standard 55-2017 ISO 7730	Q-Trak™ IAQ-Calc™ VelociCalc™ AirAssure™
Relative Humidity	30% to 60%		ASHRAE Standard 55-2017 ISO 7730	Q-Trak™ IAQ-Calc™ VelociCalc™ AirAssure™
Ventilation (outdoor air)	Recommended volume/person minimum depending on type of space and activity		ASHRAE Standard 62.1-2017	Q-Trak™ IAQ-Calc™ AccuBalance™ VelociCalc™
Ventilation (CO ₂)	No more than about 700 ppm over outdoor ambient		ASHRAE Standard 62.1-2010	Q-Trak™ IAQ-Calc™ VelociCalc™ AirAssure™
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™ VelociCalc™ AirAssure™

Indoor Air Quality Instruments from TSI® Incorporated



(Model 7545)

IAQ Calc™ Indoor Air Quality Meters

Models 7515, 7525, 7545

- Low-drift NDIR CO₂ sensor for stable, accurate readings
- Sampling function records multiple point measurements
- Ergonomic, over molded case design

Models 7525 and 7545:

- Temperature and relative humidity measurements help determine thermal comfort
- Calculates percentage outside air from either CO₂ or temperature
- Electrochemical sensor measures CO (Model 7545)
- Displays up to three parameters
- TSI® LogDat2™ software permits easy transfer of data to a computer
- Data can be reviewed on-screen, or downloaded to a computer
- Statistics function displays average, maximum and minimum values, and the number of recorded samples

	7515	7525	7545
CO ₂	×	×	×
CO			×
Temperature		×	×
Humidity		×	×
Percentage outside air		×	×
Dew point		×	×
Wet bulb temperature		×	×
Data logging/downloading		×	×
Statistics	×	×	×
Review data		×	×
Certificate of Calibration	×	×	×



Q-Trak™ Indoor Air Quality Monitor

Model 7575

- Simultaneously measures CO₂, CO, temperature and humidity
- Calculates dew point, wet bulb and percent outside air
- Large graphic display
 - Displays up to 5 measurements
 - On-screen messages and instructions
- One instrument with multiple plug-in probe options including VOCs and air velocity
- Store up to 39 days of data collected at one-minute log intervals
- Compatible with TrakPro™ Data Analysis downloading software used for data logging, analysis and documenting results

	<p>Volatile Organic Compounds (VOC) Indoor Air Quality Probes Models 984, 985, 986, 987</p> <ul style="list-style-type: none"> ▪ Pre-calibrated plug-and-play accessory probes for TSI® Q-Trak™ Monitor 7575, VelociCalc™ Meter 9565, and Airflow™ Instruments TA465 Meter ▪ Compact design with ergonomic handle ▪ Four versions available with multiple measurement capability <ul style="list-style-type: none"> – 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
	<p>Q-Trak™ XP Indoor Air Quality Monitor Model 7585</p> <ul style="list-style-type: none"> ▪ Simultaneously measures and logs up to 20 IAQ parameters, including Particulate Mass concentration and gas – in one instrument ▪ Measures PM1, PM2.5, PM10 size fractions and total particle concentration ▪ Accommodates up to six optional, pre-calibrated gas sensors <ul style="list-style-type: none"> – Includes CO₂ sensor – Additional optional gas sensor includes CO, VOC, CH₂O, O₃, CL, NH₃, H₂S, NO, NO₂ ▪ Field calibration and plug and play replacement of sensors minimizes downtime ▪ Measures temperature, relative humidity and barometric pressure with wet bulb and dew point calculations ▪ Large touch-screen with intuitive navigation ▪ Multiple data logging formats include manual, continuous and scheduled saving ▪ Analyze data with TrakPro™ Ultra Software
	<p>AirAssure™ Continuous Indoor Air Quality Monitors Models 8144-2, 8144-4, 8144-6</p> <ul style="list-style-type: none"> ▪ Continuously monitor common indoor air quality parameters ▪ Deploy one or more monitors to track real-time indoor air quality conditions in your space using TSI® Link™ Solutions cloud-based software ▪ Installs in less than 10 minutes <p>Models</p> <ul style="list-style-type: none"> ▪ 8144-2 measures CO₂ and VOC ▪ 8144-4 measures CO₂, VOC, CO and H₂CO ▪ 8144-6 IAQ measures CO₂, VOC, SO₂, O₃ and NO₂ <p>All models measure particulate matter (PM), barometric pressure, temperature and relative humidity.</p>

 <p>(Model 9545)</p>	<p>VelociCalc™ Air Velocity Meters Models 9535, 9535-A, 9545, 9545-A</p> <ul style="list-style-type: none"> ▪ Accurate air velocity measurement ▪ Easy to read display ▪ Simple to operate ▪ Calibration certificate included ▪ Simultaneously measure temperature and velocity ▪ Displays up to three measurements simultaneously ▪ Calculates volumetric flow and actual/standard velocity ▪ Data log 12,700+ samples and 100 test IDs ▪ Download data with LogDat2™ software Articulated probe versions available (9535-A and 9545-A) ▪ Measures humidity (Model 9545 and 9545-A)
 <p>(Model 9565)</p>	<p>VelociCalc™ Multi-Functional Ventilation Meters Models 9565, 9565-A, 9565-P, 9565-X</p> <ul style="list-style-type: none"> ▪ Optional “smart” plug-in probes, including VOC, CO₂, and rotating vane probes ▪ Accommodates up to two K-alloy thermocouples ▪ Built in workflows for calculating the percentage of outside air and heat flow ▪ Duct leakage testing when used with the PANDA ▪ Large graphic display <ul style="list-style-type: none"> – Displays up to five measurements simultaneously – On-screen messages and instructions – Program for local language ▪ Intuitive menu structure allows for ease of use and setup ▪ Multiple data logging formats ▪ Download data with TrakPro™ and/or LogDat2™ software
 <p>(Model 9650 shown with optional 982 IAQ probe)</p>	<p>VelociCalc™ Multi-Functional Ventilation Meters Models 9600, 9630, 9650</p> <ul style="list-style-type: none"> ▪ Large, high-resolution color display ▪ Intuitive menu structure allows for ease of use and setup ▪ Optional smart plug-in probes, including thermoanemometer, rotating vane and IAQ probes ▪ Input for one K-alloy thermocouple ▪ User-customizable soft keys for quick access to common functions ▪ Calculate the percentage of outdoor air with IAQ probe ▪ Built in duct traverse grid workflows (9650) <ul style="list-style-type: none"> – ASHRAE 111 log-Tchebycheff – ASHRAE 111 Equal Area – EN 12599 – EN 16211 ▪ Integrated magnets for hands-free operation ▪ Transfer CSV data files directly to PC with included USB cable

 <p>(Model 8380)</p>	<p>AccuBalance™ Air Capture Hood Model, 8380*</p> <ul style="list-style-type: none"> ▪ Ergonomic design and ultra-light weight for easy, one-person operation ▪ Automatically senses and displays supply or return flows, saving time on the job ▪ Back pressure compensation ensures accurate readings ▪ Detachable digital micromanometer offers flexibility to use in multiple applications ▪ Includes Swirl X Flow Conditioner for use with twist or swirl type supply air diffusers <p>*Model 8380 is only available outside of North America. Please see the Alnor EBT731 for availability in North America.</p>
 <p>(Model 8715 shown with optional Velocity Matrix probe)</p>	<p>DP-Calc™ Micromanometers Models 5815, 5825, 8715*</p> <ul style="list-style-type: none"> ▪ Measure differential and static pressure from -15 to +15 in. H₂O (-3735 to +3735 Pa) ▪ Calculate and display velocity when using a Pitot tube <p>Added Features Model 5825:</p> <ul style="list-style-type: none"> ▪ Calculates flow ▪ Variable time constant ▪ Statistics ▪ Stores 12,700+ samples and 100 test IDs ▪ Programmable K factors <p>Features 8715*:</p> <ul style="list-style-type: none"> ▪ Accurately measures pressure, velocity and flow ▪ Auto-zeroing pressure sensor ▪ Automatic density correction ▪ Intuitive menu structure ▪ Integrated Log-Tchebycheff duct traverse calculations ▪ Bluetooth® communications ▪ Accommodates optional pitot, air flow (straight pitot), temperature/relative humidity, velocity matrix, or thermoanemometer probes for use in multiple applications <p>*Model 8715 is only available outside of North America. Please see the Alnor EBT730 for availability in North America.</p>

	<p>SidePak™ Personal Aerosol Monitor (Photometer) Model AM520</p> <ul style="list-style-type: none"> ▪ Real-time mass concentration measurement and data logging for "in-the-field" data analysis ▪ Dual display and data logging of mass concentration and response concentration on one screen ▪ Stores up to 10 custom calibration factors on the instrument ▪ Robust impactors enable reliable size fraction measurements at higher aerosol concentrations over longer run times ▪ High capacity battery ▪ Color OLED display ▪ User-selectable alarm levels to alert workers to high aerosol concentrations ▪ Utilizes TrakPro™ v5 Data Analysis Software ▪ Custom calibration factor calculator to simplify calibration factor process ▪ Ability to name custom calibration factors and upload them to the instrument ▪ Enhanced alarm features to include response concentration alarm value
 <p>(Models 8530/8530EP, 8533/8533EP)</p> <p>(Models 8532/8534)</p>	<p>DustTrak™ II and DRX Aerosol Monitors Models 8530, 8530EP, 8532, 8533, 8533EP and 8534</p> <ul style="list-style-type: none"> ▪ Real-time mass concentration readings and data-logging allow for data analysis during and after sampling ▪ Simultaneously measure size-segregated mass fraction concentrations corresponding to PM₁, PM_{2.5}, Respirable, PM₁₀, and Total PM size fractions ▪ Easy-to-use graphical user interface with color touch-screen for effortless operation <p>Desktop Models 8530, 8530EP, 8533, and 8533EP</p> <ul style="list-style-type: none"> ▪ Energy-efficient, long lasting external pump for continuous, unattended, 24/7, outdoor monitoring applications (Model 8530EP/8533EP only) ▪ Long life internal pump for shorter work-shift or IAQ sampling applications (Model 8530/8533) ▪ Gravimetric reference sampling capability for custom reference calibrations ▪ Automatic zeroing (with optional zero module) to minimize the effect of zero drift ▪ STEL alarm setpoint for tracking 15-minute average mass concentrations ▪ Standard and advanced calibration capabilities for consistent accuracy (Model 8533/8533EP) <p>Handheld Models 8532 and 8534</p> <ul style="list-style-type: none"> ▪ Long life internal pump for continuous sampling ▪ Single-point data collection for walk through surveys ▪ Lightweight design with ergonomic handle for portable applications



P-Trak™ Ultrafine Particle Counter (CPC)

Model 8525

- Detects and counts ultrafine particles (smaller than 1 micrometer)
- Real-time ultrafine particle counter
- Solves tough IAQ problems
- Track ultrafine particles to their source
- Easy to use
- Data log information

TSI and TSI logo are registered trademarks of TSI Incorporated in the United States and may be protected under other country's trademark registrations. The Bluetooth® word mark and logos are registered trademarks owned by Bluetooth SIG, Inc. and any use of such marks by TSI is under license. Other trademarks and trade names are those of their respective owners.



Knowledge Beyond Measure.

TSI Incorporated – Visit our website www.tsi.com for more information.

USA	Tel: +1 800 680 1220	India	Tel: +91 80 67877200
UK	Tel: +44 149 4 459200	China	Tel: +86 10 8219 7688
France	Tel: +33 1 41 19 21 99	Singapore	Tel: +65 6595 6388
Germany	Tel: +49 241 523030		

