

HVAC Assessment Handbook

A Practical Guide to Performance
Measurements in Mechanical Heating,
Ventilating and Air Conditioning Systems



ENERGY AND COMFORT

Ventilation Test Instruments



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HVAC Assessment Handbook

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Measurements in Mechanical Heating,
Ventilating and Air Conditioning Systems

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Introduction

Heating, Ventilating, and Air Conditioning (HVAC) relates to systems that perform processes designed to regulate the air conditions within buildings for the comfort and safety of occupants or for commercial and industrial processes or for storage of goods. HVAC systems condition and move air to desired areas of an indoor environment to create and maintain desirable temperature, humidity, ventilation and air purity.

Depending on geographic location and building construction, various types of interior climate control systems help ensure that interior spaces are maintained at comfortable levels year-round. With today's energy conservation concerns, buildings are constructed to be much tighter, reducing the level of natural exchange between indoor and outdoor air. As a result, more and more buildings rely on mechanical conditioning and distribution systems for managing air.

A properly operated HVAC system finds the often-delicate balance between optimizing occupant comfort while controlling operating costs. Comfort is an important issue for occupant satisfaction, which can directly affect occupants concentration and productivity. At the same time, controlling these comfort and health parameters directly affects HVAC system operating costs in terms of energy, maintenance and equipment life.

This handbook is not intended to be a comprehensive guide for all possible issues associated with HVAC system operation and maintenance. There are volumes on the subject. Rather, it highlights some measurements and techniques that can be used to evaluate HVAC systems for optimum operation.

Building Design and Operation

Some basic considerations that need to be addressed when specifying the equipment needed to control and condition the air should include the size and physical layout of the building, which determines equipment requirements such as the size and type of fans, boilers, coils and filters. A thorough understanding of the entire system, from the outdoor air intake to the furthest diffuser is essential to good system design. It is also important to understand the specific purpose of the space and activities taking place. This will greatly influence the building's conditioning requirements. This further dictates appropriate equipment and the capacity needed to meet those requirements. Design parameters must account for cooling load, heating load, ventilation and filtration requirements. Other considerations that directly impact the HVAC system include the number of people in each space, interior elements like wall placements, furnishings and equipment that may create barriers to impede airflow and distribution. Internal loads such as lights, computers and other equipment that may produce heat, humidity or otherwise affect ambient air conditions must also be considered.



The design of air distribution equipment in today's buildings presents challenges for the mechanical engineer. Equipment selection must combine properly engineered products, which efficiently provide conditioned air to the occupied space while blending in with the architectural features of the interior. Considerable time and money can be spent developing and purchasing the appropriate mechanical components, system controls, ductwork and piping. If components are selected improperly, the HVAC system will operate inefficiently, not meet requirements and create cost overruns to correct the situation. Since one aspect of the system affects another, proper selection of every component, regardless of apparent significance, is imperative.

Efficiency vs. Effectiveness

With any mechanical ventilation system, there is a trade-off between optimizing occupant comfort and controlling operating costs. Common measurements for assessing effectiveness or the level of comfort among occupants include a variety of parameters such as temperature, humidity, air velocity, ventilation, vibration and noise. Individual perception plays a significant role since comfort is both physical and psychological and can vary greatly by individual. What is comfortable for one person may be too warm for the next and too cool for a third.

When maximizing the operating efficiency of a system, a number of factors must be considered including fuel source and cost, electrical consumption, air filtration, equipment life, maintenance costs and more. These expenditures are often very visible. Controlling them has a direct impact on the day-to-day cost of building operation and can impact a company's profitability. Reducing HVAC operating expenditures to a point where occupants are dissatisfied has other costs associated with it, including increased costs due to absenteeism, loss of people due to employee turnover, recruiting, training and decreased productivity to name but a few. So it is important to balance comfort against cost so both are optimized.

Special Considerations



Some situations require special attention with respect to the HVAC system. This section lists a few examples from the many situations where HVAC systems play a key role in success or failure.

Some applications have strict requirements for precise temperature and humidity control. These include food processing, storage of perishables, certain industrial processes, chemical processing and storage, computer rooms, green houses and other applications where a few degrees difference in temperature could mean the ruin of costly product or equipment.

In some laboratories and health care facilities, the potential for the migration of dangerous or infectious substances is a concern. Patients recovering from surgery, transplants or other immune compromised conditions are especially prone to airborne infections and may require special consideration with respect to filtration and ventilation. (TSI has published a brochure featuring instrumentation for managing differential pressure in health care facilities. It can be viewed on our web site at <http://www.tsi.com/documents/Hospital.pdf>).

Cleanrooms in the semiconductor industry require very stringent filtration and control of ambient air. Here, even a small breach in contamination control could mean the loss of a considerable amount of valuable product.

Many buildings have adjacent or underground parking areas and controlling the introduction of vehicle emissions into the building is imperative. Smoking restrictions have been implemented in public buildings, restaurants and many corporate facilities. In general, proper exhaust and ventilation is an important concern to rid the building of unwanted contaminants.

During construction or renovation, special attention must be paid to the HVAC system to contain and control unwanted airborne contamination and prevent it from migrating to other areas of a building. Maintaining negative relative pressure in the construction area is an important consideration along with special filtration and, perhaps, dedicated exhaust.

Another matter that has come to light recently is the idea of protecting buildings from the infiltration of dangerous material, particularly airborne nuclear, biological or chemical (NBC) agents. Here special consideration must be given to controlling and protecting the outdoor air intake, filtration, the level of uncontrolled leakage and the ability of the system to purge a building. Mechanical ventilation systems

have various controls to regulate airflow and pressure in a building that can be essential in an emergency response situation. In some cases, with sufficient time, it may be wise to shut off the building's HVAC and exhaust system to help prevent the introduction of NBC agents. Other times, the system can be used to regulate pressure and airflow to control the migration or spread of unwanted agents through the building. Special training for building personnel may be required for them to recognize situations requiring certain action and be familiar with the proper plan of action.

Indoor Air Quality

Indoor air quality (IAQ) is a growing concern today. Concern with energy conservation has made building construction nearly airtight, which, in turn, has made proper ventilation more important than ever. People today are spending the majority of their lives indoors, more than 90% of the time according to the EPA. Managing indoor air quality can have a big impact on the satisfaction, productivity and health of occupants. Three general categories of contaminants can impact IAQ: biological, chemical and particle related pollutants. The key to effective IAQ management is finding and controlling the exact source of the contamination. It is not acceptable to treat symptoms. The problems will not go away until the source is removed, repaired or controlled so that creation and migration of unwanted pollutants is completely arrested.

TSI has published a practical guide to address some of the key issues in IAQ management today. It can be viewed on the TSI web site at <http://iaq.tsi.com>.

Outdoor Air

An issue that is frequently overlooked and ends up being dealt with after the fact is the impact of the surrounding environment on a building. Too often, aesthetic consideration places outdoor air intakes in areas of the building that may be exposed to all sorts of problems. The quality of the indoor air will be affected if an intake is facing heavy traffic, industrial discharges, or other sources of unwanted pollutants. Such situations may require special filtration, could lead to premature loading of filters, increased maintenance and cleaning costs and unexpected wear and tear on the equipment. Corrective action may involve upgrading to more effective filters or, in extreme cases, relocating the outdoor air intake.

The EPA enacted the National Ambient Air Quality Standards in reaction to the Clean Air Act passed in 1970. The Clean Air Act established two types of national air quality standards. **Primary standards** set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. **Secondary standards** set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. The Clean Air Act requires the EPA to set National Ambient Air Quality Standards (NAAQS) (see table on page 19) for pollutants considered harmful to public health and the environment. The NAAQS is instrumental in providing guidelines for the location of outdoor air intakes.

The EPA Office of Air Quality Planning and Standards (OAQPS) has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" pollutants. They are listed in the table on page 19, near the end of this book.



Key Performance Measurements

What – Air handling equipment

The following are some examples of the many different types of HVAC systems available today.

Single-zone system—serves a single, temperature-controlled zone. Found in small shops or computer rooms where the environment and usage generally remains the same.

Multi-zone system—delivers conditioned air to several zones from a single, central air-handling unit. The zones served should have similar thermal load requirements such as offices or classrooms. Conditions in each space are maintained by temperature controllers in each zone, which vary the amount of heated or cooled air to be delivered.

Constant volume system—the volume of air delivered to an occupied zone by this system does not change, or changes very little. The discharge temperature is controlled in the zone by a temperature controller, which activates heating and/or cooling coils.

VAV (Variable Air Volume) system—air volume to a zone is adjusted via a damper that responds to a zone thermostat controlling heating and cooling coils. VAV boxes can be found on multi-zone system duct runs that are new to the building or are a considerable distance away from the central air handler unit.

Heat pumps—a type of refrigeration system that draws out heated indoor air in the warm weather to keep the occupied space cool, and removes heat from the outdoor air and transfers it to the inside during cold weather periods.

Unit ventilator—a single, self-contained system found in hotel/motel rooms, schools, garages, and other applications where individual room environments must be maintained separately.

Why

The HVAC system can be viewed as the cardiovascular and respiratory system of a building, supplying clean conditioned air to all areas. The air handler is the heart of the system since this is where outdoor air is drawn in, filtered, conditioned and mixed with return air. This “supply” air is then distributed through a network of ducts to and from areas of the building. Basic components include dampers, fans or blowers, heating and cooling coils, air filters, boilers or furnaces, compressors, ductwork to convey the air and diffusers or registers to distribute the air evenly. A number of controlling mechanisms, including thermostats, sensors and actuators, help control the distribution of air throughout a building.



Routine preventative maintenance is the key to avoiding premature wear and tear on components that can lead to repair or premature replacement. Repair and replacement can be costly and often lead to inconvenient, even unacceptable downtime. There are situations, such as in hospitals, where unexpected system downtime is simply not an option for a 24/7 operation. Therefore, it is critical to be aware

of the system’s condition and components, to perform routine cleaning and do minor repairs. This will extend equipment life and allow for major repair or replacement to be scheduled at a time when it has less impact on disrupting business. Over time, “dirt” can lead to the demise of an HVAC system. At a minimum, unwanted contaminants can inflict damage to equipment that leads to premature wear and tear, increased maintenance costs, increased cleaning costs and lower operating efficiency.

When

It is recommended that a regular, routine schedule be established for checking system components. Some items may need inspection more often than others, so establish a procedure that indicates when each element should be checked. Periodic inspection of components is critical to identify and remedy potential problems at the earliest stage when corrective action can be done in less time and usually at considerably less expense than waiting until failure occurs.

Where

Most of these inspections must be made directly inside the air handler and ductwork. Air handlers often have access doors for performing inspections, service, repair or replacement. Other areas of the air handler and ducts are often equipped with small access holes for inspection and taking duct traverse measurements. These holes are re-sealed with a small plastic plug, which can be removed for future measurements.

How

Outdoor air is introduced to the air handler through an inlet vent that is typically controlled with a damper, either manually or mechanically operated. This outdoor air is mixed with the return air, and this mixed air passes through an air filter. The filtered air may then be conditioned by heating coils, cooling coils, moisture reduction devices, and humidifiers. The conditioned air is then passed through a final filter and delivered via ductwork to all the zones of the building. Damper positioning sensors, temperature controls, volume flow and humidity controls are some of the measurement parameters that should be continuously monitored to give an indication of system performance or to signal alarms if any control aspect is outside of acceptable limits. Fan belt tension, clogged drain pans, dirty heating/cooling coils and fan blades, misaligned filters, and other mechanical components may require visual inspections, performed on a periodic basis.

Economic implication—too often, the ventilation system is taken for granted until some sort of mishap occurs. Unforeseen, preventable problems can have serious consequences, including work stoppage, spoiled inventory, and unexpected equipment service or replacement costs. Many of these problems can be prevented by implementing and following scheduled maintenance tasks.

What—Combustion analysis

Why

Boilers, furnaces, water heaters and other HVAC system components that use combustion to generate heat need to be monitored and tuned regularly for peak efficiency and safe operation. A few key measurements help improve fuel economy, reduce undesirable emissions and improve safety.

When

Some companies have an “annual check-up” usually done just before the heating season starts. Others tune combustion equipment when they switch from heating to cooling and vice versa. When equipment is tuned for optimum operation, it is done under a certain set of conditions. Because outside conditions are constantly changing, the more they vary from when the tune-up was done, the less efficient the equipment will perform. To optimize efficiency, periodic spot checks should be done and adjustments made to ensure that equipment is performing at its best.



Where

Combustion measurements are performed where the equipment is located. A few measurements in the exhaust stack are compared to ambient conditions outside the stack to determine how well the equipment is functioning.

How

Combustion analysis consists of measuring several gases, temperature and pressure. Gases typically include oxygen (O₂), carbon monoxide (CO), carbon dioxide (CO₂), nitrous oxide (NO), nitrogen dioxide (NO₂) and sulfur dioxide (SO₂). Comparative measurements indicate whether equipment is performing at peak efficiency. It is also very important with any combustion equipment to check carbon monoxide (CO) levels. Carbon monoxide is a colorless, odorless, toxic gas that when inhaled readily mixes with blood to inhibit the blood's ability to carry and exchange oxygen. Exposure can lead to health problems and even death. Even small levels of CO are reason to immediately investigate and to take corrective action. The temperature of supplied combustion air is compared to the temperature of the exhaust gas. A simple differential pressure measurement can determine if the flue draft is functioning properly and exhausting the combustion gases and particles.

TSI has prepared a manual titled Combustion Analysis Basics that can be downloaded from our web site at no charge at <http://combustion.tsi.com>.

Economic implication—the following chart demonstrates the importance of maintaining optimum operating efficiency in combustion equipment.

Boiler HP	Fuel Cost			
	\$0.75	\$1.00	\$1.50	\$2.00
100	\$3,635	\$4,847	\$7,271	\$9,694
200	\$7,271	\$9,694	\$14,541	\$19,389
300	\$10,906	\$14,541	\$21,812	\$29,083
500	\$18,177	\$24,236	\$36,354	\$48,471
800	\$29,083	\$38,777	\$58,166	\$77,554

Table 1. Possible savings per year with a 5% improvement in boiler efficiency (based on 3000 hours per year of operation).

What – Air velocity



Why

Fans are used to introduce, distribute, recirculate and exhaust air in a building. Checking air velocity periodically at various points assures that air is being distributed as expected through the ventilation system. Measurements should be made on both the supply and return air sides of the system. Air movement or velocity has an impact on perceived comfort by occupants.

When

Regular “spot” checks should be performed in different locations throughout the building to be sure that the system is performing as expected. Special attention should be paid whenever something in the building changes that may impact the HVAC system’s performance. Examples include switching over from heating to

cooling, remodeling, rearranging a space, enlarging or reducing the area being served and adding or subtracting people.

Where

Air velocity measurements should be made at diffusers or registers both on the supply and return sides of the system. Measurements should be made in the ductwork, paying particular attention to sections close to dampers, transitions, elbows, branches and take-offs to be sure air is moving as expected throughout the system and that nothing is impeding air movement. For highest accuracy, measurements should be made in a straight section of duct roughly the equivalent of 7.5 duct diameters downstream and 3 duct diameters upstream from anything that may cause a disturbance in air flow.

How

A number of instruments typically called “anemometers” reliably measure air velocity. Some types use rotating vanes that measure air speed based on how fast moving air turns a small windmill-like device. Other styles use thermal anemometer technology that employ “hot wires” or thermistors that compare small changes in resistance and display it as an air velocity measurement. Instruments can be used to conduct real-time surveys and some instruments allow the data to be recorded so different locations can be compared or a study can be done over time in a given location to help assess system performance or occupant comfort.

Economic implication—proper ventilation, air velocity and even distribution are key contributors to perceived air quality and comfort. People tend to perform better when they are comfortable and offer fewer distractions to others due to complaints. It is good practice to make routine checks to ensure the HVAC system is performing as expected in each occupied zone.

What – Ventilation

Why

Ventilation refers to the amount of fresh air supplied throughout the building. In the interest of energy conservation, air is typically recirculated and mixed with some amount of fresh air at the air handler. Introducing fresh air helps dilute any airborne contamination and exhausts it out of the building faster.



According to industry studies, over half of the indoor air quality complaints reported can be traced to problems in ventilation. ASHRAE Standard 62 offers detailed recommendations pertaining to ventilation in occupied spaces.

When

Assessment should be done on a regular basis. In climates with wide shifts in weather conditions, this analysis should be done at a minimum when the system is being changed over from heating to cooling and vice versa. Ventilation should always be checked whenever an occupant complaint triggers an investigation and when changes or modifications are made to the HVAC system or to physical characteristics of a building.

Where

Measurements need to be made in all occupied spaces within a building. It is important to remember that in buildings with multiple air handling systems each system must be evaluated separately, almost like another building.

How

A good indicator of proper ventilation in a space is the level of CO₂, a natural by-product of respiration, combustion and other processes. Elevated levels of carbon dioxide can be an indication that additional ventilation or outdoor air may be needed. ASHRAE Standard 62 recommends that indoor levels not exceed roughly 700 ppm more than outside ambient conditions. Higher levels of CO₂ may cause slight drowsiness, enhance odors or give the impression of stale air. Increased levels are rarely considered a health hazard since concentrations up to 10,000 ppm can be tolerated by most people in good health without any ill effects. Reducing CO₂ levels in an occupied space is accomplished by increasing the number of air exchanges and/or percentage of outdoor air supplied to the conditioned space.

To ensure that a building is properly ventilated, it is important to take CO₂ measurements in occupied areas, air distribution zones, at varying heights and compare them to the outdoor level. To get accurate data on CO₂ levels in an occupied space, data should be logged over a period of time so any fluctuations can be analyzed. CO₂ levels will naturally fluctuate during the work day based on occupancy and facility usage. During the evening hours, when the building is unoccupied, CO₂ levels generally drop. As the day begins and workers arrive, CO₂ levels will tend to rise.

Keep in mind that recommended guidelines should be followed closely so that too much fresh air is not introduced unnecessarily. Careful regulation of the introduction of fresh air, which in turn must be filtered, conditioned and distributed, will help keep energy costs down.

Many commercial systems employ a system control called Variable Air Volume (VAV) or on-demand ventilation. Monitors are placed in the system, usually in the return air duct, to measure the level of CO₂ or temperature or both. When the measured level falls outside some predetermined “set points”, the monitor triggers an automatically controlled damper to increase or decrease the amount of outdoor air introduced. Make sure that the system is in a fully operating mode and not cycling automatically when taking ventilation measurements.

The percentage of outside air can be calculated with the following equation using either temperature or CO₂ levels:

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

* measurement refers to either CO₂ or temperature

What – Air volume and number of changes

Why

ASHRAE Standard 62 recommends a certain volume of fresh air be supplied to various areas in a building, which is dependent on the number of people present and the nature of the activity taking place. This is typically expressed as cubic feet per minute (cfm), cubic meters per hour (m³/hr) or liters of air per minute (l/min) per person.

When

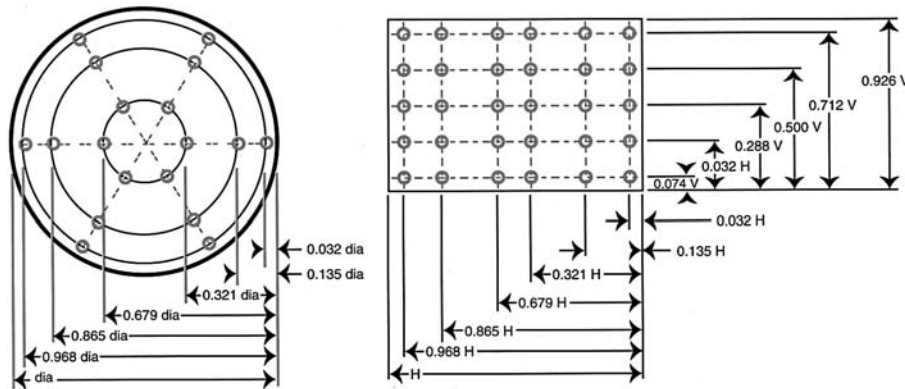
Proper volume flows and air exchanges per hour should be verified any time changes or renovations occur that may affect the HVAC system. Volume flow verification should also be done when there are increases in occupant complaints, higher than normal operating costs, odors, abnormal ventilation noise or when changes in building differential pressures create noticeable conditions such as unexpected drafts and difficulty opening doors. Fresh air volume and air changes can be compared to recommendations in ASHRAE Standard 62. If measurements conform to these guidelines, it is a good general indicator that the system is performing properly.

Where

Measuring volume flow can be accomplished in several ways: performing duct traverses with a thermoanemometer or micromanometer with pitot probe and then doing the necessary conversions, using a capture hood directly on the supply diffuser or exhaust grille or with a swinging vane anemometer with diffuser probe.

How

First, the percentage of outside air being supplied to an area must be determined (see ventilation section, page 7). Air velocity is rarely uniform in an air duct since the shape of the duct, frictional forces, bends, branches, dampers and transitions all affect the movement of air. For this reason, when average air velocity is used to determine volume flow, a special technique called the log-Tchebycheff method should be employed. As shown in the diagrams below, several velocity measurements should be taken in the cross-sectional area of a duct to ensure the most accurate estimate of average velocity is determined. This average velocity can then be multiplied by the cross-sectional area of the duct (in square feet) to give an estimate of volume based on velocity. ASHRAE Standard 111 has additional details on measuring air flow in ducts.



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

Another method of obtaining air flow volume is through the use of capture hoods which give a quick, direct reading of air volume at a given location, such as an air diffuser. Capture hoods are also very useful in balancing an HVAC system to ensure that the correct amount of air is being supplied to each area and that proper differential pressure relationships are maintained.

Note: Capture hood flow measurements can be affected by several ventilation system parameters. Therefore, it is recommended that capture hood readings be compared with those from a duct traverse calculation. A properly executed dust traverse is considered a reliable method for reference in making this comparison and can be used to characterize system flow at outlet diffusers. A field correction factor known as a 'K' factor can then be applied to capture hood measurements to compensate for unusual configurations that may impact the measured flow.

The percent outdoor air calculated in a ventilation assessment can then be multiplied by the volume of air entering a space to determine the amount of fresh air being delivered in cubic feet per minute. Compare this to the recommendations in the



tables provided in ASHRAE Standard 62. The following gives 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

Air flow can also be used to determine the number of air changes that occur in a space over a period of one hour. This is accomplished by determining the supply air flow rate in CFH (cubic feet per hour) and dividing it by the total volume of a given space (length x width x height) to come up with the number of air exchanges per hour. Likewise, the calculated fresh air percentage can be applied to this air change calculation to determine changes of fresh air over time in a given space. The exchange of air between inside and outside is important in diluting and removing unwanted contaminants.

What – Thermal Comfort

Why

The perception of thermal comfort varies by individual. Thermal comfort is influenced by a combination of temperature, humidity, and air flow and can be affected by parameters outside of the HVAC system such as time of day, activity level, clothing, number of individuals in a space and other factors. It can have a profound impact on human concentration and productivity. If people are uncomfortable, they may also distract other people with their complaints. ASHRAE Standard 55 recommends temperature range guidelines perceived as “comfortable” to be 73 to 79°F (22.8 to 26.1°C) during the summer and 68 to 74.5°F (20 to 23.6°C) during winter. Indoor relative humidity levels should generally be maintained between 30 and 65 percent to be perceived as comfortable by most individuals. The Standard suggests a goal of satisfying 80% or more of the occupants.

A flow of air is created when a differential pressure condition exists between spaces, and a sensation of draft is perceived when this difference is high enough. Drafts below 45 to 50 fpm are generally not noticed by occupants and, therefore, maintaining levels near this is recommended. Too little draft may create a sensation of stuffiness or stale air.



When

Periodic checks should be conducted in different locations throughout the building to be sure that the system is performing as expected. Special attention should be paid whenever something in the building changes that may impact the HVAC system’s performance. Occupant complaints should be investigated whenever they occur and appropriate corrective action taken.

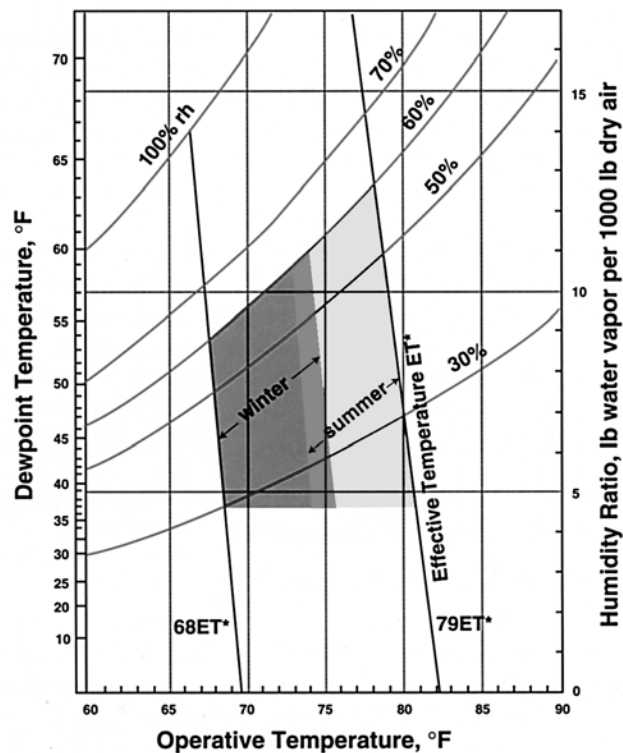
Where

Temperature can vary widely throughout a building and the sensitivity to temperature is influenced by air movement, proximity to windows and doors, clothing worn and other factors. Therefore, it will not likely be sufficient to set a temperature goal and adjust the system from one location. Intermittent measurements should be taken throughout occupied spaces and the system adjusted accordingly. Likewise, humidity measurements should be taken throughout all occupied spaces to ensure that the HVAC system is distributing the desired amount of properly conditioned air to all areas. Complaints of draftiness should be investigated by tracking air currents to their sources. Remedies for undesirable draft may include redirecting diffuser throw patterns, installing plastic “draft curtains” in open doorways, rebalancing a zone to get better supply and exhaust flow correlation, along with other options.

How

As comfort pertains to the ventilation system, the key comfort parameters involve temperature, relative humidity, draft and ventilation. Measurements should be taken in all occupied areas. Portable instruments that measure these parameters in real-time or record values over time are very helpful in making accurate assessments and identifying areas where corrective action may be needed.

Temperature, humidity, and air flow are often linked together to provide a measure of thermal comfort. ASHRAE Standard 55 offers guidelines and the chart at the right illustrates thermal comfort ranges for summer and winter. The objective is to adjust the system to satisfy at least of 80% of the occupants.



What – Airborne contaminants as related to Indoor Air Quality (IAQ)

Why

Some substances can become airborne and pose a threat to individual health, causing symptoms ranging from temporary irritation to chronic problems and, ultimately, death in extreme cases. Three basic groups of contaminants are of concern:

- Gases or chemical vapors such as CO, NOx, SOx, volatile organic compounds (VOCs) and radon.
- Particles, particularly those less than 4 microns in diameter defined as respirable.
- Biologicals, including animal parts, bacteria, viruses and plants such as fungi, mold and pollen.

While many airborne contaminants are tolerated by most individuals, some people have acute sensitivities to certain substances when they reach a threshold limit. In a group of people, for example, only one individual may be affected. If complaints occur and it is suspected they may be air related, they should

not be treated lightly. An investigation should be done quickly, the source(s) identified and remedial action completed in a timely fashion.

When

Routine checking may be a good proactive measure. Any time a complaint is received and there is reason to believe that it may be associated with airborne contamination, a complete investigation is warranted to identify and isolate sources followed by determining and executing proper corrective action.

Where

Identifying specific sources becomes the challenge in dealing with airborne contaminants. They are driven by air movement and differential pressure (high to low), so often the “problem” is dispersed throughout an area. In addition to differential air pressure and air movement, unwanted contamination, including gases and airborne particles, will migrate from relatively warm to cool areas.



How

Surveys should be done in real time if possible, and in some cases depending on the contaminant, it may be necessary to take samples and have them analyzed by an environmental laboratory. Specific protocol for procedures and transport is usually provided by the laboratory when conducting sampling for further analysis. In the case of biological substances, it is critical to control moisture. Before any clean-up or treatment is done, make sure the source of any moisture from plumbing, condensation or a breach in the exterior envelope is identified and corrected. Unless the moisture source is removed, other efforts will probably end in vain. In addition to cleaning the intake air through proper filtration, controlling air movement, differential pressure and temperature within the building are the primary tools that will allow you to manage the movement of airborne contaminants.

Economic implication—health insurance premiums increase, potential litigation, increased absence, increased cleaning and maintenance costs, reduced equipment life, more frequent filter changes can all have a negative impact on the operating costs of a building.

What – Differential Pressure

Why

Small airborne particles and gases are transported by air movement and will also migrate from areas of relatively high to low differential pressure as well as from relatively warm to cool areas. Managing differential pressure between the inside and outside and between different areas of the building by regulating supply and return air volumes is a key means of controlling the migration of unwanted contaminants. Verifying and maintaining building pressures is essential in preventing infiltration of outdoor contaminants and moisture into the building envelope. If the building is maintained at a negative pressure in relation to the outdoors, then the negative pressure can “pull in” outdoor contaminants through gaps or cracks in the building structure. Building pressures can also impact the difficulty of opening or closing doors to the outside, which is a particular concern to the elderly or handicapped, especially in emergency situations.

When

Proper building pressures should be checked whenever renovation or reconstruction might affect the HVAC system and alter its performance from the original design. Seasonal changes usually involve a change over from winter to summer or summer to winter mode. If mixed signals are sent to the automated controls affecting damper positioning for outdoor air or return air, for example, then more or less air may be introduced, which could result in varying building pressures and creating unwanted conditions.

Where

Monitoring differential pressures between a room and a hallway or anteroom is a common practice with hospital isolation wards, laboratories, high-tech semiconductor manufacturing plants and other critical areas. Maintaining a negative differential pressure within a lab or isolation room helps prevent the spread of contaminants to the rest of the building. Measuring duct static pressures and comparing them to previous measurements is a quick way of determining if changes have occurred to the system flow rate. Taking velocity pressure measurements within HVAC ductwork provides a means of determining how much airflow is being delivered. This information can be used to balance the system to meet ventilation specifications, cut down on operating costs and increase efficiency.

How

Pressure measurements are obtained using some type of analog or digital manometer. Manometers have a positive and a negative pressure port that can be connected to a pitot-static probe for performing duct velocity pressure measurements. The velocity pressure can then be converted to velocity or volume flow rates using simple formulas. Most digital models perform these calculations automatically. Differential pressure measurements between two separate areas are accomplished by placing the meter with one pressure port open to atmosphere in one area, connecting a hose to the other port and running it under a door or connecting it to a through-the-wall pressure tap to another area.

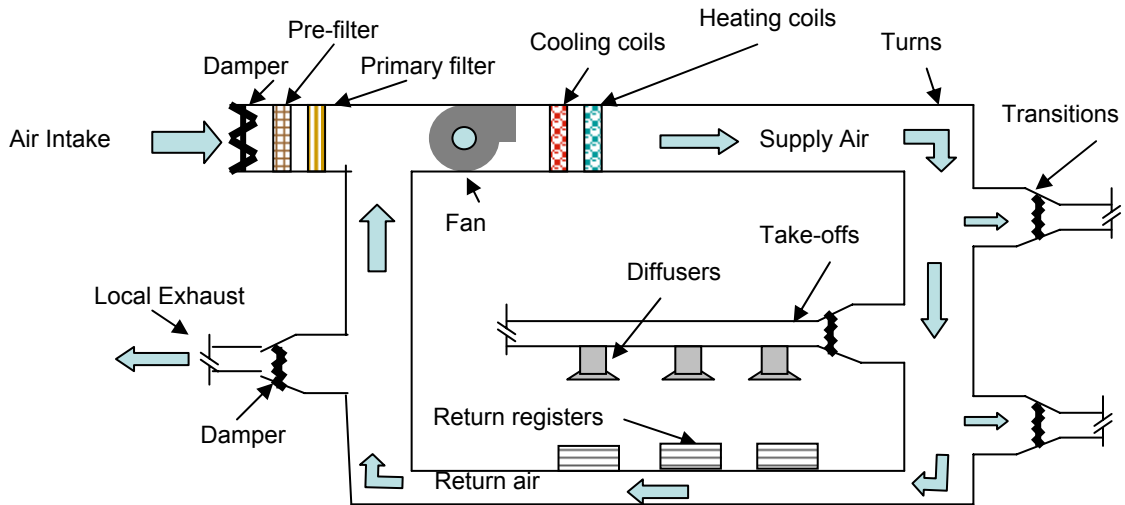
Economic implication—controlling unwanted migration of contaminants from outside sources or from within the building will reduce cleaning and maintenance costs. It can be used to help control the spread of infectious or contagious diseases. Pressure controls will help contain the migration of other airborne contaminants that may be irritating, harmful or even deadly.

What – System Pressure

Air pressure becomes an issue in the HVAC system itself. Fans or blowers bring outdoor air in, mix it with some of the return air and then distribute the air to all parts of the area being served by that system. System pressure actually has three components:

- Static Pressure—the driving force to move air
- Velocity Pressure—the additional force exerted when air contacts an obstruction
- Total Pressure—the sum of static and velocity pressure

Fans are “sized” to meet the requirements of adequate air distribution. Characteristics of the blower, including size and rotational speed, combined with the resistance of the ductwork determine how much air is moving and the pressure in the HVAC system (see diagram for example of some HVAC components that can affect system pressure).



Typical System Elements Affecting Pressure

Why

Each element in a system such as a damper, filter or coil resists air flow, causing a pressure drop. When the drops across each element are added together in a run, the result is total pressure loss. Too much drop results in inadequate air volume, affecting the system’s ability to meet design requirements and resulting in poor ventilation in a building. Another key consideration is that as debris accumulates in filters or on the surface of other components, their resistance to air movement increases. This increased resistance also decreases the volume of air supplied.

When

A routine schedule to check pressures across system elements should be established based on the size of the system, maintenance costs, filter costs and activities in the building. Further testing should be performed whenever there is a change in the building such as an addition, remodeling or rearrangement. Variations from system design requirements should be investigated and corrected before they lead to expensive repairs or replacement.

Where

Access holes in ductwork should be placed on the up and downstream side of components that affect system pressure by causing a drop. Dampers, filters, and coils are examples of system components that should be checked periodically.

How

Taking pressure measurements using a portable manometer can be done quickly and easily. Manometers are equipped with a positive and negative port which can be connected to access ports in the duct on each side of the element being checked. For supply side measurements, the positive port should be positioned upstream and the negative, downstream. For return lines, these should be reversed.

Economic implication—Routine checks along the system will help determine when cleaning is necessary or filters need to be changed. Proactive monitoring of system pressure measurements can be vital in reducing maintenance costs, extending the life of the equipment, maximizing filter efficiency and preventing costly downtime.

What – Air Filters



Air filter elements capture particles and prevent them from entering the conditioned air stream. Filters are available in a wide range of sizes and configurations depending on the application. Examples of filter media include paper, sponge foam, spun glass and pleated woven bags. Other filters include electrostatic particle arresting types where the filter media is electrically charged to make it more effective in attracting and capturing particles. Activated charcoal filters are used to address unpleasant odors associated with vapors or gases, but they should always be used in conjunction with a particle filter.

Why

Filters are placed ahead of key system components mainly to extend life, reduce maintenance and repair costs and prevent damage from dirt and other pollutants. A secondary usage for filters is to prevent contaminants from dispersing throughout the ventilation system and into occupied areas, which could pose health hazards or create a dirty, dusty environment.

When

It is recommended that filters be thoroughly checked each time they are changed to be sure there are no tears or breaches and that gaskets are tight. Periodic checks between changes will ensure that they are functioning properly and prevent unwanted particle contamination from entering the HVAC system. Overlooking or minimizing the significance that air filters are properly installed and functioning will decrease the life of system components, increase maintenance costs and disperse contaminants throughout the building.

Where

Air filters are found in different locations depending on the application. Mechanical equipment rooms, process and shop areas, storage areas, and warehouses typically have a pre-filter located at the input of the air handler prior to the juncture of the outdoor and return air ducts. A secondary filter may also be found after the fan but prior to the main trunk. The main purpose of this filtration system is to remove larger particles and to protect the heating and cooling coils from dirt build-up.

Analytical laboratories, cleanrooms, hospitals, pharmaceutical R & D areas and similar facilities may have two different types of pre-filters at the air handler input, and also at the final filter stage after the air handler. The pre-filters, having ratings of 75 to 85% arrestance and 25 to 40% dust spot efficiency, remove a large number of the airborne particles. The final filters would then have some higher efficiency rating like 98% arrestance and 80 to 85% dust spot efficiency. This type of setup is very effective on fumes and smoke as well as particles.

How

A filter's ability to stop particles is a function of several factors, including fiber material and density, as well as particle characteristics such as size, shape, density, mass, electrical charge and speed. As filters become loaded with particles, they become more and more effective in blocking additional particles until they reach a point where they begin to impede air flow and tax the air moving equipment. That can cause damage and shorten equipment life.

Today, most filters are evaluated based on ASHRAE Standard 52.2 and are assigned a MERV (minimum efficiency reporting value) rating. This rating represents the resistance to particle penetration based on ranges of average particle size and also shows a minimum pressure drop across the filter. *See table 2 on page 17.*



The filter effectiveness ratings are determined by testing a filter with a known number of particles of a given size at a known air velocity and comparing the value to the number of particles exiting the filter. In an actual installation, regular checks using a particle counting instrument is an effective means of evaluating filters to be certain they are performing as they should, have no tears or holes and that gaskets and support framing are tight.

Measuring the pressure drop across a filter is a cost effective method for verifying filter and system performance. An air filter should be changed when the filter fills up with debris and creates an excessive pressure drop, resulting in reduced airflow through the filter. Periodic visual inspections and monitoring the pressure drop across the filter with a mechanical or digital manometer is a simple solution for general ventilation system maintenance.

Applications requiring contaminant-free air such as pharmaceutical labs, biological research labs, hospital operating and intensive care rooms, isolation areas and some high tech assembly areas require the use of HEPA (High Efficiency Particulate Arresting) filters. These filters trap 99.97% of all particles and are rated at 0.3 microns in diameter, a size which is among the most difficult size to stop. The HEPA filter is composed of randomly positioned micro glass fibers woven into a thick bed of material that may be several inches thick. There is no direct or straight line of flow through the filter, but a random, twisted path that forces multiple particle impacts with fibers, greatly increasing the chance of being captured.

Economic implication—optimizing filter usage involves careful monitoring of the filter's performance. An air filter's efficiency actually improves as it traps material since the captured particles actually help trap additional particles, but this is true only up to the point where the pressure required to pull or push air through the filter exceeds the system design and may cause damage to the system. The key is to not change filters too often, thereby adding to filter replacement costs, but also not too infrequently to the point where air flow is impeded.

MERV	ASHRAE 52.1 Equivalent Dust Spot Efficiency	Composite Average Particle Size Efficiency (PSE) %			Min. Final Resistance (in.wg)	Typical Controlled Contaminants	Typical type of Filter	Typical Applications
		Range 1 0.3 - 3.0 µm	Range 2 1.0 - 3.0 µm	Range 3 3.0 - 10.0 µm				
1	N/A	-	-	E ₃ < 20%	0.3	Pollen, moss, insects	Disposable	Pre-filter
2	N/A	-	-	E ₃ < 20%	0.3	Dust mites, sanding dust	Washable	Roughing
3	N/A	-	-	E ₃ < 20%	0.3	Paint dust, textile fibers	Electrostatic	Roughing
4	N/A	-	-	E ₃ < 20%	0.3	Carpet fibers	1" to 3" Electronic AC	Residential
5	N/A	-	-	20 < E ₃ < 35%	0.6	Powdered milk	Electronic Air Cleaner	Residential
6	N/A	-	-	35 < E ₃ < 50%	0.6	Household and cement dust	Electronic panel	Residential
7	N/A	-	-	50 < E ₃ < 70%	0.6	Hair spray, fabric protection	Electrostatic cartridge	Light commercial
8	N/A	-	-	70% < E ₃	0.6	Mold spores	Pleated	Commercial
9	40 to 45%	-	E ₂ < 50%	85% < E ₃	1.0	Nebulizer drops, welding fumes	Box filter	Paint booths
10	50 to 55%	-	50 < E ₂ < 65%	85% < E ₃	1.0	Coal dust, auto emissions	Residential EACs	Heavier commercial
11	60 to 65%	-	65 < E ₂ < 80%	85% < E ₃	1.0	Lead dust, milled flour	Box filter	Health care
12	70 to 75%	-	85% < E ₂	90% < E ₃	1.0	Legionella, humidifier dust	Bag filter	Health care
13	80 to 90%	E ₁ < 75%	90% < E ₂	90% < E ₃	1.4	Copier toner, face powder	Industrial EACs	Smoking areas
14	90 to 95%	75 < E ₁ < 85%	90% < E ₂	90% < E ₃	1.4	Insecticide dust, most smoke	Box filter	Hospital labs
15	> 95%	85 < E ₁ < 95%	90% < E ₂	90% < E ₃	1.4	Droplet nuclei (sneeze) cooking oil	Box filter	Isolation areas
16	-	95% < E ₁	95% < E ₂	95% < E ₃	1.4	All bacteria, most tobacco smoke	Box filter	General Surgery

Table 2. MERV 1 - 16 Air Cleaning Devices

Conclusion

Proper system design accounts for building type and size, layout, surrounding area, the nature of activities taking place, the number of occupants, climate and other factors, making each situation distinct. A good understanding of the entire HVAC system from the outdoor air intake to the furthest diffuser is essential for good management.

In optimizing system operation, a number of economic factors must be considered, including fuel source and cost, electricity consumption, filtration, life of the equipment, maintenance costs and more. These must be balanced against occupant comfort and special manufacturing or storage considerations.

Making and analyzing certain key measurements is essential for optimizing the HVAC system performance. Information collected gives you the tools to make the correct decisions. More information can be found in the Ventilation Test Instruments brochure that can be viewed on the TSI web site at <http://vti.tsi.com>.

Sources for Information Relating to Managing Mechanical HVAC Systems

The following is a list of some of the organizations that may be able to offer additional information on air quality, heating, ventilating and air conditioning issues.

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 Indoor Air Quality Council (AmIAQ) – www.iaqcouncil.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
American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) –
www.ashrae.org
American Society of Safety Engineers (ASSE) – www.asse.org
Building Air Quality Alliance (BAQA)
British Occupational Hygiene Society (BOHS) – www.bohs.org
Building Owners and Managers Association (BOMA) – www.boma.org
Center for Disease Control and Prevention (CDC) – www.cdc.gov
Heating, Refrigeration, Air Conditioning Institute of Canada (HRAI) – www.hrai.ca
Healthy Buildings International (HBI) – www.hbi.com.au
Indoor Air Quality Association (IAQA) – www.iaqa.org
International Facility Management Association (IFMA) – www.ifma.org
International Society of Indoor Air Quality and Climate (ISIAQ) – www.isiaq.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
Sheet Metal & Air Conditioning Contractors' National Association (SMACNA) – www.smacna.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. Department of Energy (DOE) – www.energy.gov
U.S. Environmental Protection Agency (EPA) – www.epa.gov
World Health Organization (WHO) – www.who.int

There are also numerous seminars, training programs, trade publications, text books, web sites and other media available that are dedicated to air quality, heating, ventilating and air conditioning installation, operation, testing and maintenance. There are far too many to adequately include in this guidebook.

Standards and Guidelines

National Ambient Air Quality Standards

POLLUTANT	STANDARD VALUE *		STANDARD TYPE
Carbon Monoxide (CO)			
1-hour Average	35 ppm	(40 mg/m ³)	Primary
8-hour Average	9 ppm	(10 mg/m ³)	Primary
Nitrogen Dioxide (NO₂)			
Annual Arithmetic Mean	0.053 ppm	(100 µg/m ³)	Primary & Secondary
Ozone (O₃)			
1-hour Average	0.12 ppm	(235 µg/m ³)	Primary & Secondary
8-hour Average	0.08 ppm	(157 µg/m ³)	Primary & Secondary
Lead (Pb)			
Quarterly Average	1.5 µg/m ³		Primary & Secondary
Particulate (PM 10) <i>Particles with diameters of 10 micrometers or less</i>			
Annual Arithmetic Mean	50 µg/m ³		Primary & Secondary
24-hour Average	150 µg/m ³		Primary & Secondary
Particulate (PM 2.5) <i>Particles with diameters of 2.5 micrometers or less</i>			
Annual Arithmetic Mean	15 µg/m ³		Primary & Secondary
24-hour Average	65 µg/m ³		Primary & Secondary
Sulfur Dioxide (SO₂)			
Annual Arithmetic Mean	0.030 ppm	(80 µg/m ³)	Primary
24-hour Average	0.14 ppm	(365 µg/m ³)	Primary
3-hour Average	0.50 ppm	(1300 µg/m ³)	Secondary

* Parenthetical value is an approximately equivalent concentration

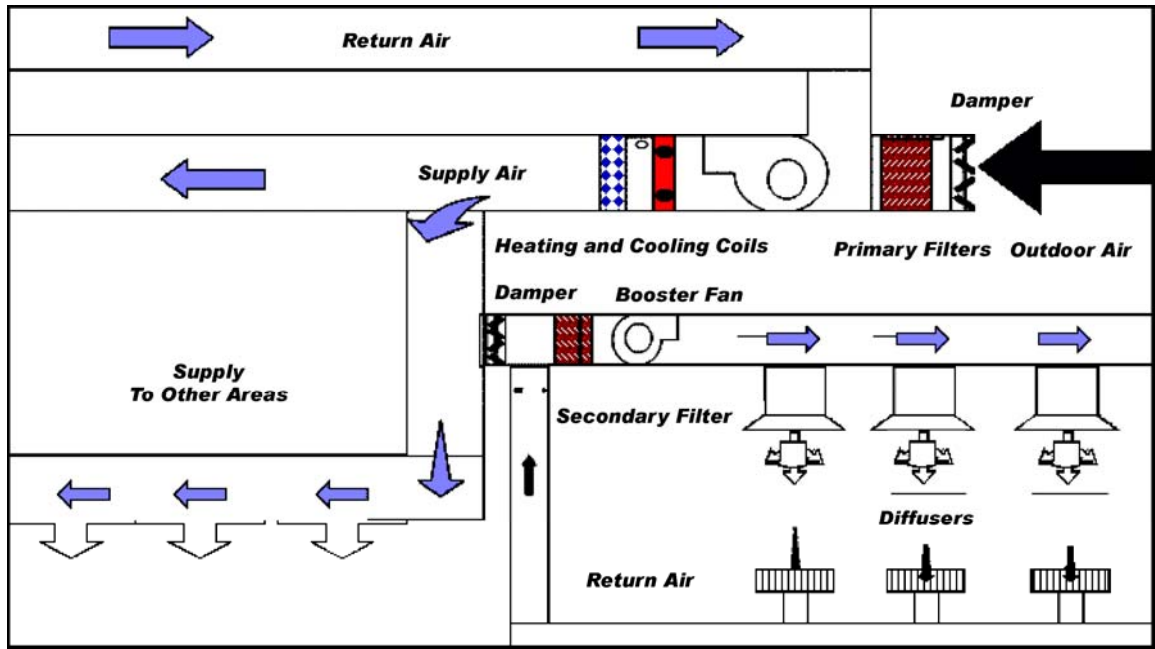
Air Quality Guidelines

Parameter	Limit/Range		Reference	TSI Instrument
Temperature	Summer 73 to 79°F Winter 68 to 74.5°F		ASHRAE Standard 55-1992	Q-TRAK IAQ-CALC TH-CALC VELOCICALC
Relative Humidity	30% to 65%		ASHRAE Standard 55-1992	Q-TRAK IAQ-CALC VELOCICALC TH-CALC
Air Movement	0.8 ft/s or 0.25 m/s		WHO	VELOCICALC DP-CALC ACCUBALANCE
Ventilation (fresh air)	15 to 60 cfm/person minimum depending on type of space		ASHRAE Standard 62-1999	Q-TRAK IAQ-CALC TH-CALC
Ventilation (CO ₂)	About 700 ppm over outdoor ambient		ASHRAE Standard 62-1999	INSPECTAIR Q-TRAK IAQ-CALC
Particle Concentration in Cleaned HVAC Systems	1.0 µg/100cm ²		NADCA 1992-01	P-TRAK DUSTTRAK SIDEPAK
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













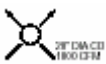

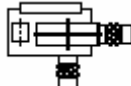




GLOSSARY

- Absolute Pressure—pressure referenced to a vacuum or gauge plus atmospheric pressure
- Air Handling Unit (AHU)—system elements including air intake, fan (blower), filters, coils and humidification/dehumidification equipment
- Airflow—the movement of air
- Back Pressure—static pressure increase due to restriction of air flow
- Balancing—adjustment of the HVAC system to ensure operation in accordance with design
- Diffuser—an outlet or grill designed to direct air into a desired pattern
- Duct Traverse—a method of determining average air velocity in a duct, which can be multiplied by the duct area (in square feet) to calculate air volume or flow rate
- Face Velocity—air velocity perpendicular to a fume hood sash opening
- Gauge Pressure—pressure referenced to atmospheric pressure
- Manometer—an instrument for measuring pressure
- Pitot Tube—a small bent tube which measures velocity by means of differential pressure
- Return—the half of an HVAC system which returns air from various areas of a building to some type of air handler
- Rotating Vane Anemometer—an instrument for measuring velocity related to revolutions over time
- RTD—resistive temperature device
- Static Pressure—force per area that would be exerted by a moving fluid on an object in order to move it
- Supply—the half of an HVAC system which delivers air from some type of air handler to various areas of a building
- Thermal Anemometry—a means of detecting air velocity using the heat loss of a heated wire or film
- Thermocouple Effect—voltage developed by joining two dissimilar metals to measure temperature differential
- Thermometer—a device for measuring temperature
- Velocity Pressure—positive pressure caused by moving air; related to air speed squared

Typical Mechanical Ventilation System



COMMON HVAC SYMBOLS

UNIT HEATER (PROPELLER) 	UNIT HEATER (CENTRIFUGAL+) 	UNIT VENTILATOR 	THERMOMETER 	DIRECTION OF FLOW 
FLEXIBLE CONNECTION 	DUCTWORK WITH ACOUSTICAL LINING 	FIRE DAMPER WITH ACCESS DOOR 	MANUAL VOLUME DAMPER 	
AUTOMATIC VOLUME DAMPER 	EXHAUST, RETURN OR OUTSIDE AIR DUCT - SECTION 	SUPPLY DUCT SECTION 	CEILING DIFFUSER SUPPLY OUTLET 	CEILING DIFFUSER SUPPLY OUTLET 
FAN AND MOTOR WITH BELT GUARD 	FLOOR REGISTER 	TURNING VANES 	LOUVER OPENING 	LINEAR DIFFUSER 

VTI Instruments from TSI



VELOCICALC®

Multi-Functional Ventilation Meters

Models 9555, 9555-A

- Extended air velocity range of 0 to 10,000 ft/min (0 to 50 m/s) using a thermoanemometer, and 250 to 15,500 ft/min (1.27 to 78.7 m/s) using a pitot probe
- Displays and data logs up to 5 measurements simultaneously
- One instrument with multiple plug-in probe options including:
 - Thermoanemometers
 - Rotating vanes, 50 to 6000 ft/min (0.25 to 30 m/s)
 - Ultrasonic air velocity, 50 to 6000 ft/min (0.25 to 30 m/s)
 - CO, CO₂, temperature, and humidity
 - K-alloy thermocouples
 - Draft
- Language selection



VELOCICALC®

Rotating Vane Anemometers

Model 5725

- Air velocity range of 50 to 6,000 ft/min (0.25 to 30 m/s)
- 4-inch diameter rotating vane head for measuring fluctuating flows
- Sweep mode makes it easy to sweep across an area for one overall measurement
- Calculates average, maximum and minimum values, and records the number of samples
- Flow rate calculated automatically



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
- Flowrate calculated automatically
- Durable telescoping probe with etched length marks
- Humidity measurement [Models 9545 and 9545-A]



VELOCICALC®

Air Velocity Meters

Models 9515, 9525

- Air velocity range of 0 to 4,000 ft/min (0 to 20 m/s) (Model 9515)
- Intrinsically safe (Model 9525)
- Temperature readings
- Telescoping probe (Model 9515)



Model 9515



ACCUBALANCE®

Air Capture Hoods

Models 8371, 8372, 8373, 8375

- Accurate direct air flow readings from a vent, diffuser, or grille
- Balancing mode makes it easy to adjust dampers (8372 and 8373)
- Automatically sums flows and calculates statistics for branches and systems (8372 and 8373)
- Automatic flow direction indicator (8373)
- Light weight
- Variety of hood sizes available



TH-CALC™

Thermohygrometers

Models 7415, 7425

- Temperature, humidity, and dew point
- Data logs up to 40,000 samples (Model 7425)
- Calculates % outside air (Model 7425)
- Calculates wet bulb, absolute humidity and humidity ratio (Model 7425)



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)



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)

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



CA-CALC™
Combustion Analyzers

Series 6000, 6100, 6200

- Measurements and calculations include O₂, CO, CO₂, draft, air and stack temperature, efficiency, and excess air
- NO, NO₂, SO₂, and high CO sensors optional
- Factory-calibrated replacement sensors



Air Velocity Transducers
Models 8455, 8465, 8475

- Three versatile sensor types
- Four standard probe lengths
- User-selectable velocity range, output and time constant
- Easy to wire, set-up and configure
- Optional display power supply available

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