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Indoor Air Quality Update™

A Guide to the Practical Control of Indoor Air Problems, from Cutter Information Corp.

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Checking Out Building Ventilation

Commercial- and public-building occupants and managers often need to check the adequacy of ventilation when occupants report indoor air quality problems. Investigators frequently find significant design and operational deficiencies with HVAC systems.

In this article we describe some practical ways to evaluate ventilation system performance related to maintaining good IAQ. First we discuss some of the reasons why ventilation systems fail to perform adequately. Then we describe a step-by-step process for investigating ventilation systems in IAQ complaint buildings. Lastly, we report on some useful tools for ventilation measurements.

In This Issue

Why Ventilation Systems Fail

Dr. James Woods of Virginia Tech in Blacksburg, Virginia, has investigated and reported on common deficiencies in HVAC systems. In buildings he investigated, he found that system designs often provided inadequate outside air (75%) and inadequate air distribution to occupied spaces (75%). He also found that equipment design problems resulted in inadequate filtration of outdoor air (65%), inadequate drain pans and drain lines (60%), contaminated ductwork and duct linings (45%), and malfunctioning humidifiers (20%). Operational problems identified by Woods included inappropriate control strategies (90%), inadequate maintenance (75%), and thermal and contaminant load changes (60%).

Poor Design for IAQ

Many IAQ problems in HVAC systems originate with designs and operational programs that try to optimize thermal control and energy efficiency without adequate consideration of indoor air quality. To achieve energy-oriented goals, there was a trend (starting back in the late 1950s) toward reducing outside air-supply quantities and airflow quantities to reduce energy consumption. If less outside air requiring tempering is brought into a building, less energy is required to heat or cool it and to control its humidity. If less air circulates around a building, less energy is required to operate the fans, less fan capacity is required to circulate the air, and less material is required for ductwork to handle the air movement.

Many HVAC systems vary the volume of outside air, the amount of air distributed to the interior spaces, or both, in order to conserve energy. In some buildings there is little or practically no outside air brought into the building by the ventilation system. Woods and others have found insufficient outside air ventilation in the overwhelming majority of IAQ complaint buildings.

Filtration and air cleaning are also potential sources of IAQ problems. Outside air or recirculated air generally contains contaminants. Depending on the type, timing, and concentrations of these contaminants, the building HVAC system may not be adequate to sufficiently control contaminant levels. In some cases, outside air is so contaminated that it might be more technically and economically feasible to clean recirculated interior air than to use outside air supply. It is always important to evaluate the quality of outdoor air being used to dilute contaminants generated indoors.

Sources of Contaminants

Ventilation systems in many

buildings (some authorities would say most buildings) can be improved. However, remember that the adequacy of a building's ventilation system depends on the contaminants that it must dilute or remove. The ventilation requirements of a building are, strictly speaking, a function of the building's contaminant source characteristics. Therefore, it is important to identify contaminant sources and to investigate potentially strong or unusual contaminant sources before or concurrent with investigating ventilation systems. Controlling contaminants at their sources is generally easier and more economical than controlling them by ventilation.

The important aspects of contaminant sources are their type, strength, location, and timing of emissions. Only by knowing these things about sources can one determine ventilation requirements. These requirements are the basis for evaluating the adequacy of ventilation system performance.

Inadequate Operation Schedules

In some buildings supply fans operate intermittently. This leaves space unventilated some of the time even while occupied. Such systems operate on what is known as a "duty cycle": fans are periodically shut off to conserve energy.

Many building HVAC systems operate only during normal work hours or slightly longer. Shortening the hours of HVAC system operation can result in poor indoor air quality. While many of the contaminant sources diminish or cease when occupants leave, some, such as emissions from building materials and furnishings, continue while the building is vacant. If their temperature rises when the HVAC system is off, materials might actually emit more.

Poor HVAC Maintenance

It is not uncommon to find buildings where the HVAC system is poorly maintained and filters are not replaced regularly. In the worst cases, filters are missing, sensors and other control components are missing or disconnected, and the system is just "limping" along. In many cases, filters simply are not replaced frequently enough, leading to reduced air flow, increased loads on fans, and potentially to microbial contamination.

We have observed public and private sector buildings where the responsible management personnel were convinced that the building was being well-serviced and maintained. However, upon inspection, we found gross defects in equipment and operation. Many of these problems would have been obvious to any reasonably informed observer. We conclude that in most of these cases there was either no informed observer or, worse, insufficient concern.

Building Maintenance

Sometimes, janitorial activities performed during unoccupied periods are not accompanied by adequate ventilation to remove fumes from deodorants, polishes, waxes, shampoos, spot removers, and other odorous products. Some of the fumes may include solvents that have irritant or toxic effects on occupants. The residual vapors may assault occupants when they reenter the building in the morning. It is necessary to provide some ventilation during and following maintenance activities or to thoroughly ventilate the building before re-occupancy.

Investigating Ventilation Systems

The following is an outline process for determining the adequacy of building ventilation. It is necessarily general in nature, and not all steps will be applicable to all buildings. However, most of the steps are applicable in most buildings and will prove useful in assessing the adequacy of ventilation. The major steps range from getting subjective opinions from occupants to reviewing design documentation, outside air quantity and quality, air pathways, and space air distribution. Variable-air-volume systems, air cleaners, and humidity-control devices are also discussed.

It is important not to assume that investigating part of a building can

Table 1 — Investigating Ventilation Systems

Review Occupant Complaints
Review Design Documentation
Determine Air Pathways Through the Building
Assess Outside Air Quantity
Evaluate Space Air Distribution
Check Variable-Air-Volume Distribution Systems
Inspect Air Cleaners
Inspect Humidity Control Devices and Associated Chemicals

provide assurance that the entire building is similar. In many cases, pollution sources and their problems are local. Ventilation system defects or malfunctions may also be local. And not all complaints will necessarily stem from the same causes. Even though there may be problems or complaints throughout the building, there may be various causes and remedies for the problems in different parts of the building.

1. Review Occupant Complaints

Review information on occupant complaints about the building environment. The first step in conducting an investigation is to identify the nature, timing, and location of discomfort, irritation, and health complaints. Identify patterns of the occurrences, if possible, to narrow the scope of the investigation and focus it on suspect components.

Occupants are important sources of information about the functioning of the HVAC system. If an occupant is complaining about air quality or thermal comfort, in most cases there is something that can be done to address the cause and alleviate the complaint.

a. Time of occurrence

If complaints and responses are logged, review the log. Determine whether problems occur at certain times of the day or week, or in certain months or seasons of the year. Determine whether the complaint pattern corresponds to any particular pattern of HVAC system operation, maintenance, or other observable changes or activities.

b. Location

Determine whether complaints are associated with certain parts of the building. Are complaints concentrated in areas served by a single thermostat, zone, or air-handling unit? Sometimes complaints may be confined to certain floors or areas of a building; this allows the investigator to limit the investigation to the ventilation equipment serving that area.

c. Type of complaints

Are all of the complaints similar or identical? Do most occupants or only a few of the occupants in an area, zone, or building experience the problems? Are the problems obviously attributable to the ventilation system, or could they be caused by other sources? This is particularly important in large buildings served by multiple air handlers. For example, are the problems confined to a single zone or area served by a single air-handling unit? Do they occur on a particular side or floor of the building? Is there a pattern to their occurrence by time of day or day of the week?

d. Realistic expectations

It is reasonable to expect most building occupants to be comfortable and satisfied with the air quality in their office environment. It is also reasonable to find that a few occupants are not comfortable or satisfied. Ventilation system design based on ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.) standards does not assume that all occupants will be satisfied. Deciding whether the dissatisfaction level is acceptable must be done on a case-by-case basis.

2. Review Design Documentation

To understand a building's ventilation, review documentation of the design of the HVAC system. Design documentation normally includes construction documents (contract plans and specifications). It should also include documentation of the loads assumed for the basis of the design and the design criteria. Other documentation relied upon by the designers is not usually available other than from the designers themselves. Also, obtain a report of the testing and balancing work when the building was built (and any subsequent adjustments).

In some cases, data sheets (specifications, submittals, "cut sheets") may be available for the equipment and components selected by the designers and used in the construction. These are necessary to supplement the original drawings and specifications which may not be specific regarding the equipment actually installed in the building. Performance data for these parts of the system are part of the data sheets. Whenever available, "as built" drawings will provide a record of what was actually constructed; this frequently differs from the original construction documents.

3. Determine Air Pathways Through the Building

Determine how outside air (including soil gas if necessary) enters and leaves the building. The quantity of air entering equals the quantity of air leaving the building. It is insufficient to check only air entry; you must check exit points as well to understand air flow through the building. Determine the location and magnitude of flows in and out of the building in the following areas.

a. Mechanical ventilation system

Check ventilation system air intakes, exhausts, and exhaust fan discharges. Look for supply air intakes located near obvious or potential sources of contamination such as loading docks, dumpsters, garages, passenger drop-off points, roadways, and exhausts from kitchens or bathrooms. Entrained exhaust or other contaminated air may be getting into the outside air supply. This is frequently found in problem buildings and should be one of the first things to examine. Also, standing water or cooling towers upwind from air intakes can be the source of microbial contaminants or chemicals.

Evaluate the quantity of air entering and leaving the building by using airflow measuring devices such as anemometers or Pitot tubes. Evaluate these flows under part- and full-load conditions and at various times to determine the scale of variations that occur over time. (See portions of the article on the EPA Headquarters' building study later in this issue of *IAQU* for some additional ideas on airflow measurements.)

b. Doors and windows

Openings in the building can also be sources for entry of unwanted contaminants as well as for considerable quantities of outside air. Use qualitative measures of airflow at these locations under various conditions of HVAC system operation. The direction of flow might change as the HVAC system modulates or weather changes. If the flows appear large (indicated by high velocities over significant areas), even for short periods of time, it might be important to quantify these flows.

c. Ventilation system openings such as "gravity" fans

Simple devices such as roof-mounted "gravity" fans can move significant quantities of air and account for effects on airflows. Stair towers, pipe chases, and elevator shafts can also move significant quantities of air. Examine their operation and evaluate the quantity of air moved under various conditions.

d. Leakage points

Air leakage can be a significant fraction of air exchange with the outdoors. Determine the location, direction, and approximate magnitude of such leakage and include the data in the picture of total building airflow. Doors, windows, and intersections of major building components can be significant leakage points as well as openings for utilities, dryer exhausts, stove exhausts, etc.

4. Assess Outside Air Quantity

Determine the outside air quantity by measurement, calculation, or both. This can be done with tracer gases, by measuring CO_2, by measuring airflows in critical locations, or by measuring temperature and humidity. If accessible, make measurements at the outside air intakes or immediately upstream from the supply air and return air fans and in the return air plenum before the mixing chamber. Use the measurements to calculate the outside air supply quantity supplied to air distribution ducts.

a. Know what you are measuring

When measuring outside air supply, it is important to know whether the ventilation system is operating under conditions that represent minimum, intermediate, or maximum outside air supply conditions. Typically, for variable air volume systems, in warm weather (above 60 °F) or very cold weather (below 20 °F), variable air supply systems will be set to provide minimum outside air. Between those temperatures, an increase in outside air supply is normal, with maximum outside air occurring around 50 °F to 60 °F. However, each building is different, and the details of the design and operation will affect outside air supply rates. Check the design documentation and ask building operators about the system you are investigating. Observe the position of outside air intake dampers to help determine the system status during your measurements.

These measurements do not define the amount of outside air reaching occupants. That must be done through more detailed measurement processes and calculations beyond the scope of this article. (See the reference at the end of the article for a useful publication on ventilation measurement.)

b. What's enough?

Insufficient outside air supply is a common source of indoor air quality problems. In general terms, there should be a minimum of 5 to 15 cubic feet per minute per person (cfm/p) outside air entering the building when it is occupied. The standard for open office areas is 20 cfm/p. The exact quantity required depends on the types of activities, sources, occupants, and ventilation.

There is no substitute for evaluating outside air supply quantity. The closest surrogate is measurement of CO_2 levels together with counts of occupants per unit of floor area. Elevated CO_2 levels can indicate inadequate ventilation (but not with certainty). A general rule of thumb is that CO_2 concentrations should not exceed 1000 ppm, but any level greater than twice the outdoor level might indicate insufficient ventilation for the occupant load.

c. Operating schedule

Determine what the operational schedule is and the outside air *quantity programmed into the building's control system.*

Determine how the HVAC system is scheduled or programmed to operate and verify that the building actually operates as intended; often it does not. The system may not have any sensors or controls to monitor outside air quantity; most do not. Outside air quantity is usually determined indirectly by temperatures, fan speed, static pressure, and other values that are measured by devices, typically installed systems.

The quantity of outside air delivered by a ventilation system may vary considerably over time. By design, it will vary in response to changing conditions inside the building and outdoors. It will also respond to building operator instructions. It is important to assess ventilation quantity under the minimum outside air and ventilation flow conditions. It is under these conditions that problems are likely to occur or intensify, unless an important source of contaminants is located outside.

5. Evaluate Space Air Distribution

Determine whether supply air is reaching the occupants within the spaces. Short circuiting, leakage, poor mixing, or other problems can result in inadequate delivery of supply air. Use tracer gases, smoke tubes, or harmless odorants to evaluate how air moves within the HVAC system and the occupants' spaces.

The layout, flow, and relationship of supply and return air as well as the configuration of the space and its contents affects the distribution of air within the space. Under low flow conditions or where objects can block air movement, the air distribution system can fail to deliver adequate supply air to all locations. Space air distribution can account for localized IAQ problems and should always be investigated, even when only some of the occupants of a space, zone, or area are affected by poor IAQ.

a. Interior spaces

HVAC systems in many larger office buildings are designed to handle two types of loads. The "internal" load is the heat load generated by lights, occupants, office machines, and other devices throughout the building. The other type, the "external" load, is generated by heat losses and gains through the building envelope due to outside air temperatures and solar gains, primarily affecting the building's perimeter areas (near the building envelope).

Typically both the perimeter area and the interior area (the area more than 15 to 25 feet from the exterior of the building) receive the same fraction of outdoor air. However, perimeter areas often receive greater airflow in order to handle both internal and external thermal loads. The interior zone receives only enough flow to handle the internal load. Interior loads are generally constant throughout the occupancy period and are unaffected by climate. Outside air supplied to the interior zone is minimal most of the time.

One exception is a building with "economizer cycles" that uses "free cooling" by supplying 100% outside air when the outdoor air temperature is low enough to provide air at a desirable temperature but not so low as to require heating. This occurs in mild climate areas like much of the Pacific Coast and during mild weather periods in other parts of the country.

b. Perimeter offices

Perimeter offices in climates where outside air temperatures are usually too hot or too cold for free cooling often use ventilation systems to deliver tempered air to offset heat gains or losses through the exterior. Otherwise, the cooling or heating effect of the energy transmitted by and through the glass (envelope losses) would make the perimeter offices thermally uncomfortable. While this additional airflow may occur at the perimeter, it may or may not bring substantial amounts of outside air with it. This depends on the type of system used to control thermal comfort in the perimeter zone.

c. Air leakage

When the difference between inside and outside temperatures is large, there is likely to be a significant amount of infiltration (or exfiltration) through the exterior wall. Office building exteriors are relatively leaky. Andy Persily of the National Institute of Science and Technology (NIST) calculates that the exterior walls of the 14 federal government office buildings where he studied air exchange rates are, on average, six times as leaky per unit area as typical residential walls. This leakiness is beneficial if there is a shortage of outside air, especially in those spaces where air leakage is inward.

It is important to assure adequate air exchange by mechanical ventilation rather than to rely on leakage. When indoor and outdoor temperatures are nearly equal, Persily found, much less air exchange occurs. This is logical since it is the difference in temperature as well as wind that provides the driving force for the air exchange. Also, when indoor and outdoor temperatures are close, outdoor air supply will not be reduced as much by variable air volume supply systems as when the temperatures are further apart. Thus, leakage is least likely to occur when it would be most helpful in increasing outside air supply.

6. Check Variable-Air-Volume Distribution Systems

Determine airflows at minimum flow conditions in variable-air-volume (VAV) systems. In some buildings with VAV systems, airflows have been found near zero in certain locations. When VAV air distribution systems are used, airflow is reduced when the thermostat is "satisfied," that is, when air temperature is within the range beyond which the thermostat is set to "call for" more cooling or heating.

A VAV system uses a volumetric flow control box with a damper that is moved to different positions in response to the thermostat or other control device. Under extreme conditions the damper closes as far as it can until it hits the minimum setting.

The minimum position is either set at the factory or in the field (after installation in the building). This minimum setting is assigned by the design engineer, and should be such that the minimum total air supply to the space is not less than that necessary to circulate air within the space and provide for adequate air outside exchange. In some cases the minimum position has been set at zero, by mistake, malfunction, or neglect. This will result in no airflow when the system is operating at minimum flow conditions. It is important to verify the correct minimum setting and proper operation of the damper.

7. Inspect Air Cleaners

Inspect the condition and replacement log for air filters. The selection, operation, maintenance, and performance of air cleaning devices should always be investigated. Inadequate equipment or poor maintenance can result in IAQ problems including reduced flows, microbial contamination, and dirty air. Missing filters or leaky filter frames can allow air to bypass the filters without being cleaned.

8. Inspect Humidity Control Devices and Associated Chemicals

Maintaining comfortable conditions requires controlling moisture in air. Excessively dry or humid air can contribute to health and comfort problems. However, equipment used to control humidity can also be the source of microbial contaminants that enter building air. Chemicals used to treat water in humidification systems can also enter building air from the humidification systems. This equipment should be inspected for the presence of biological contaminants and the types of chemicals used to treat water should be investigated for possible irritation, odor, or toxicity.

Tools for Investigators

The following are some tools that are useful in evaluating building ventilation. Not all of these tools are necessary (or necessarily useful) on every job. They are briefly described to benefit the reader unfamiliar with them.

Hot wire anemometer

A hand-held instrument used to measure air velocity. Available in pocket-sized or larger (but still quite portable) models. Approximate cost ranges from $300 - $1,000. Available from TSI, Kurz, and other manufacturers.

Chemical smoke tubes

Glass tubes filled with a chemical which, when exposed to moist air, produce a white "smoke" that is thermally neutral, easily visible, and can be used to follow local flows at low velocity. The smoke will immediately reveal the direction and relative magnitude of airflow. The ends of the tube are broken and one end is inserted into an aspirator to push room air through the tube. They do not produce very much "smoke" in very dry air. Available from suppliers of Draeger detector tubes.

Neutral density balloons

Commercially available balloons filled with gases that, together with the weight of the balloon, result in a "floating" balloon that will stay suspended long enough to allow observation of airflow direction and magnitude.

Odorant "tracer gas" such as peppermint or other oil

A non-offensive but easily recognizable odor used for organoleptic (using the senses) detection of airflows. The oil is dispersed with a vaporizing device (such as a rubber bulb aspirator similar to that used for the smoke tubes described above). The oil can be purchased in a drug store or health food store.

Manometer for checking pressure differences ranging from 1 to 100 kPa

Used to check pressure differences between the two ends of a u-tube partially filled with a liquid, usually water, mercury, or a light oil. The difference in levels of the liquid legs indicates the pressure exerted on the instrument. Pressure differences between two spaces indicate potential airflow from the higher to the lower pressure, proportional to the pressure difference and the available pathway for the flow.

Soap bubbles

Commercial toy bubbles can be used to check air movement. While sold as play equipment for children, soap bubbles can be used when other equipment is not available to investigate airflow within a space. They are cheap, readily available, and reasonably useful. They are not as intrusive as some other equipment, although their use can certainly attract attention.

Booklet on measuring ventilation

An excellent booklet by Brüel & Kjær, manufacturer of instruments for environmental measurements, explains many of the principles of ventilation measurement and explains the basic technical information in straightforward language (see *IAQU*, February 1990). To obtain a free copy, write to Brüel & Kjær World Headquarters, DK-2850 Nærum, Denmark; Tel: +45 42 80 05 00. In the U.S., phone (508)481-7000.

News and Analysis

Fiberglass — Another Asbestos?

Industrial hygienists and facilities staff walk through a building and see that many of the walls, ceilings, boilers, and pipes are insulated with fiberglass. Also, it is torn and exposed in many places. The regular building staff wants to know if the loose material is a cancer hazard, like asbestos. How do you respond?

This is the question asked in *The State of the Workplace*, an internal bulletin from the Hazard Evaluation System and Information Service (HESIS) of the California Department of Health Services. The answer is that the question is complex and no one knows the answer for sure. Certain types of fiberglass and other man-made mineral fibers (MMMF) can cause cancer when placed directly into the lungs of laboratory animals. It is not clear, however, whether such fiber implantation is relevant to human exposure.

According to the article, there is evidence that suggests that workers exposed to large quantities of mineral fibers over long time periods have higher rates of cancer, but there are questions about the studies that show this, and they are currently being updated. It does appear certain that MMMF are not as potent as asbestos even if they do cause cancer. It may be impossible to ever determine definitively whether these materials pose any risk to exposed humans.

Essentially, asbestos causes cancer because it consists of relatively long, thin, durable fibers. There are some questions about the chemical nature of asbestos fibers as a co-factor in carcinogenicity, but these have not been resolved.

Types of MMMF

Fibers are distinguished mainly by fiber diameter. The nominal fiber diameter is defined as the length-weighted median diameter. This means that if you line up all the fibers in a sample end-to-end according to their diameter (from smallest to largest diameter) and measured the diameter of the fiber in the middle, that would be the diameter used to characterize the sample. Fibers differ as a result of manufacturing processes. Ordinary fiberglass insulation (glass wool) has a typical nominal diameter between 3 and 10 microns.

The smaller the diameter, the better the insulating properties are on a weight and a volume basis. Therefore, the historical trend has been toward smaller diameters. In the aerospace industry and other specialty applications, "microfibers" as small as one micron or less are used. These applications account for only about 1% of all fiberglass production, but the share is growing.

The larger-diameter fibers are "continuous-filament" fiberglass with nominal diameters around 15 micrometers. These are the fibers used in reinforcing plastics, specialty textiles, and fiber optics. Rock wool and slag wool (both often called mineral wool) are used exclusively for insulation. One example is the widely used asbestos-substitute for fireproofing in buildings. The nominal diameters of these fibers are typically three to eight microns.

Ceramic wool comes as high-temperature refractory fibers with nominal diameters of about two to five microns and as textile fibers with diameters of about 10 to 20 microns. Most ceramic fibers are refractory fibers.

Differences from asbestos

Asbestos fibers, on average, are much finer than MMMF. Therefore, a given weight of asbestos contains many more fibers than the same weight of MMMF. Also, asbestos fibers' lighter weight makes them more prone to become airborne, and they can more easily penetrate the respiratory tract. Also, asbestos fibers tend to split lengthwise yielding finer fibers while MMMF tend to split across the axis giving shorter fibers of the same diameter. Thus, the tendency under rough handling is for asbestos fibers to become more carcinogenic while MMMF become less so.

While certain types of asbestos fibers tend to be very durable in