Introduction

When it comes to ventilation surveys, what you are missing really can hurt you. This author has been perplexed by the vast number of ineffective and sometimes very odd workplace air contaminant ventilation systems encountered in the field over the years. Equally perplexing has been the widely observed lack of understanding on part of the system owners and even many seasoned Industrial Hygiene and Safety professionals in terms of the need to perform, as well as how to perform, periodic ventilation system assessments; what a proper assessment entails; how often assessments should be performed; and the degree of hazard presented by having no system, an ineffective system, or effective system that is malfunctioning or improperly used by staff.

Many workplaces have in good faith installed a wide variety of dilution and local exhaust ventilation systems in order to control air contaminant and flammable/explosion hazards generated by a wide variety of processes, ranging from Arc Welding to Kitchens to Dentist Offices to Embalming Operations. If these systems are not properly designed, properly used, or periodically properly assessed, not only do they not control air contaminant, fire, and/or explosion hazards, they exacerbate hazards by providing management and workers with a false sense of security. Optimal ventilation survey technique combined with system owner/operator education is paramount in insuring worker, facility, and operations protection where these systems are installed and relied upon. What you, as a manager, worker, Safety professional or Industrial Hygiene professional don’t know about ventilation surveys can hurt you in terms of chronic and acute worker overexposure to air contaminants, lost productivity, liability, facility damage, and interruption of operations. Of particular concern are the chronic health effects that are not immediately noticeable (and therefore often not subject to immediate corrective action) that may result in serious illness after years of exposure at which point it is too late for corrective action. The intent of the following information is not to raise the reader to an expert level of understanding of ventilation systems, but to provide enough information to motivate readers to review their ventilation systems and engage in a continuous improvement of these systems. Neither legal advice nor product endorsement is implied herein.

Purpose of Air Contaminant Ventilation Systems
In short, dilution and local exhaust ventilation systems serve a critical function as they:
• control mist, dust, smoke, fume, gas and vapor air contaminants in order to maintain worker exposure below the prescribed occupational exposure limits; and/or
• prevent the occurrence of flammable and explosive atmospheres in order to prevent fire and explosion.

**Local Exhaust vs. Dilution Ventilation**
Local exhaust ventilation systems are used to control air contaminants at their source whereas dilution ventilation systems control air contaminants by continuously changing out room air at a specified rate and as such do not prevent exposure, but rather lower the concentration to acceptable levels. The type of system(s) recommended for an application depends upon the nature of the operation and the level of control required.

There are countless traditional local exhaust and dilution ventilation systems; listed below for illustrative purposes are a just a few of the more commonly encountered systems from each of these categories with which you may already be familiar:

**Local Exhaust Ventilation:**

• Abrasive Blast Cabinets
• Autopsy Downdraft Tables
• Dental Lab Fume Exhaust Hood
• Electroplating Tanks
• Industrial Wastewater Pre-Treatment System Tanks
• Kitchen Hoods
• Laboratory Hoods
• Laboratory Ovens
• Medical/Dental/Veterinary Waste Anesthetic Gas (WAG) Scavenging Systems
• Metal Working Equipment
• Paint Booths
• Pesticide Sinks
• Plasma Cutting Downdraft Table
• Vehicle Maintenance Garage Hoods
• Radiator Repair Hood
• Welding Hoods
• Woodworking Equipment

**Dilution Ventilation:**

• Battery Charging Rooms
• Chlorine Storage Room
• Flammables Storage Rooms
• Patient Recovery Rooms
• Pesticide Storage Rooms
• Surgical Rooms
• Vehicle Maintenance Pits
Case Histories: Examples of Faulty Ventilation Systems
In illustration of the seemingly widespread nature of the problem described in this paper and vast array of opportunities for improvement, the following narratives depicting just a few of the more interesting ventilation system failures observed by this author over the years is offered:

• Malfunctioning kitchen hoods. Kitchen hoods are found everywhere from bowling alley kitchens to institutional kitchens to restaurant kitchens to portable field kitchen units. We ingest food daily to survive, so it is no wonder that so many are unaware of the potential serious nature of chronic overexposure to hazardous air contaminants that can be present in all types of kitchens. These contaminants include products of combustion, e.g. carbon monoxide, carbon dioxide, nitrogen dioxide and particulates; and contaminants generated by frying and inadvertent burning of foods-most notably, a variety of polycyclic aromatic hydrocarbons and the carcinogens acrylamide, benzo(a)pyrene, and formaldehyde.

• Wood working equipment in a state of disrepair with ductwork breached in several places and holes used to perform traverse measurements unplugged, resulting in the inability of the system to maintain the specified airflow, and, subsequently, appropriate air contaminant control. Most of us have innocuous encounters with wooden furniture and wood trees in our yards on a daily basis so perhaps it comes as no surprise that many have little or no awareness of some of the hazards intrinsic to wood and wood products. A variety of occupational exposure limits (OEL’s) may apply to wood dusts. Health effects upon exposure may vary with the species of wood. Western Red Cedar is a sensitizer; once sensitized, the body will quickly react on subsequent exposures, even exposures to low airborne concentrations. Oak is a listed A1 carcinogen. Other concerns are the possible presence of hazardous constituents related to wood treatments (e.g. arsenic), as well as sap, latex, lichens, and more.

• A worker located halfway between two malfunctioning water wash type ventilation booths (both of which had their water systems disconnected years earlier) applying varnish with fumes so strong a flammable gas detector audible alarm triggered and room occupants had to leave after short stints to catch their breath.

• A pesticide storage room with an ineffective ventilation system, exacerbated by large amounts of visible pesticide contamination on the floor creating a strong odor and a burning sensation to the nose and throat. Health effects from pesticide overexposure, depending on the pesticide, may include neurological effects, cancer, and reproductive effects.

• Flammables storage rooms housing drums of waste paint and solvent with open bung holes and open (non-self-closing) funnels, where the required six air changes per hour and other system requirements were not met and the fumes were overwhelming.

• Malfunctioning and misused local exhaust equipment (“smog hog” welding hoods positioned a startling several feet from the welds) for welding operations in a very active welding shop where the strong odor of welding fumes actually migrated into other areas of the facility.

• Welding canopy hoods that, as confirmed by smoke tests and ventilation survey, yielded almost zero effectiveness based on inadequate design and short-circuiting when nearby bay and pedestrian doors were left open.

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• A malfunctioning mineral oil recycling house general dilution ventilation system with an ineffective design resulting in short-circuited ventilation (intake located directly next to exhaust on the ceiling).

• Notable “dead spots” appearing on lab hoods as revealed by smoke tests complicated by failure to perform periodic ventilation surveys to assess effectiveness and make provisions for needed corrective action;

• Electroplating push/pull hoods with airflows restricted by long-term build up of salts from electroplating solutions on and in the systems, and component failure due to corrosion by long-term exposure to highly corrosive atmospheres.

• Improperly designed battery rooms resulting in inadequate airflow and positive pressure resulting in pushing hydrogen-filled air into adjacent populated work areas spreading the danger of fire and explosion beyond the battery room. Also common are air supply and exhaust vents blocked by chairs, equipment, or animal nests. In illustration of the importance of good battery room ventilation, reference is made to one impressive historical example of a battery room ventilation system failure resulting in the explosion of a UPS battery room that destroyed nearly 2,000 sq. feet of the facility in which it was located (fortunately, no one was present so no one was injured or killed at the time of the explosion). ²

What Is An Industrial Hygiene Ventilation Survey?
Each of the above ventilation system failures and others like them may be detected through periodic ventilation surveys. A ventilation survey is an organized procedure of acquiring data to quantify and characterize air flow, pressure and air quality throughout a ventilation system. An optimal ventilation survey will go further, not only measuring the air flow parameters (i.e., air flow, duct velocity, air changes per hour, etc.) for comparison to an appropriate standard, but also reviewing a variety of related issues that could impact system effectiveness. These issues could include improper use of the system by employees as demonstrated by employee interviews, system damage and other miscellaneous hindrances to the system revealed by inspection of the area, looking and listening for damaged or even missing system components, and measuring system component dimensions and placement to insure adequacy when compared to the given standard.

Using the Appropriate Ventilation Standard for a Ventilation Survey
One or more of the following standards may apply to a given system and identifying the appropriate standard can be difficult in some cases. It may reasonably be assumed that the best practice might be to go with the most conservative standard for a given system where more than one standard may apply; but in any case the standard to be used as the basis for the survey should be agreed upon in advance by the internal or external customer.

Examples of some of the many different types of standards and regulations that may apply to a ventilation system being surveyed are presented as follows:

• Occupational Safety and Health Administration (OSHA) – a wide variety of air contaminant sources are addressed; examples may be found in General Industry-29 CFR 1910.94³; Construction-29 CFR 1926.57⁴; and Shipyards-29 CFR 1915.51⁵.

• Mine Safety and Health Administration (MSHA) – One example is 30 CFR 75.326⁶ Mean Air Velocity. Providing adequate ventilation in an underground mine is the principal means of ensuring that flammable, explosive, noxious and harmful gases, dusts, smoke, and fumes are continuously diluted, rendered harmless and carried away. Insufficient air quantity allows methane and dust to accumulate, potentially resulting in a mine fire or explosion. Dust accumulations can also cause miners to be exposed to harmful levels of respirable dust, which can lead to black lung.

• American Congress of Governmental Industrial Hygienists (ACGIH) Industrial Ventilation, A Manual of Recommended Practice, current edition (28th Edition current as of the writing of this paper).⁷

• General military standards, such as United Facilities Criteria UFC 3-410-04N Industrial Ventilation⁸, which provides criteria for the design of ventilation systems that control contaminants generated from industrial processes.

• Application specific military standards such as the Armed Forces Pest Management Board Technical Guide No. 17 Military Handbook - Design of Pest Management Facilities⁹ (also known as TG17 for short). This technical guide provides the criteria and the best available technology for designing a military pest management facility or pest control shop as well as general guidelines for pesticide storage on DoD facilities.


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⁶ Mine Safety and Health Administration (MSHA), 30 CFR 75.326, Mean Air Velocity (retrieved February 22, 2015) (http://www.ecfr.gov/cgi-bin/text-idx?SID=e81d84920f7de9e3650e35b6f33ee64d&node=se30.1.75_1326&rgn=div8)


• Organizational standards, such as the National Institutes of Health Office of Research Services Division of Occupational Health and Safety Local Exhaust Ventilation Testing Protocols.12

• Certifying Body Standards, such as the National Environmental Balancing Bureau NEBB Procedural Standards for Fume Hood Performance Testing13 - establishes a uniform and systematic set of criteria for the performance testing of fume hoods used as the minimum NEBB requirements that a NEBB Certified FHT Firm shall follow when performing fume hood testing and reporting the results.

• Manufacturer standards such as the manual for the Grizzly Industrial 2HP Canister Dust Collector with Aluminum Impeller – Polar Bear Series14, which provides information on required flow rate in cubic feet per minute based on machine dust port size and type of machine serviced.

• Foreign Standards and Risk Insurer Standards – work outside the U.S. may necessitate using standards prescribed by a foreign nation. As one example, there are various such regulations and recommendations concerning the ventilation of kitchens. In Germany these are based on legal workplace regulations (ArbStättV and ASR), e.g. "ASR 3.6 - ventilation" is fundamental in regulating the ventilation of commercial kitchens, and on the recommendations of the relevant Employers' Liability Insurance Association (Berufsgenossenschaft (BG)), e.g. "GUV-R 111 - Rules for Health and Safety - Working in Commercial Kitchens", published by the German Association of Accident Insurers (2007).15

• Contract documents, engineering diagrams, or customer specifications – may supersede other standards.

Performing a Successful Ventilation Survey

Heeding the following recommendations will help insure the success of ventilation surveys.

Prepare in advance, have a copy of the actual standard selected and/or schematic present for review, and be certain to READ THE FINE PRINT on the standard or schematic and obtain all necessary measurements and data while still on site. Failure to READ THE FINE PRINT is a common and unfortunate failure mode that often results in mischaracterization or incomplete characterization of a system, or the inability to properly interpret any data collected.

Be prepared to collect all the required information during the survey visit. Having to return to sampling sites to hurriedly gather forgotten measurements and data, or worse still asking...

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facility personnel to supply forgotten measurements, has a tendency to lessen one’s credibility and decreases one’s productivity; it also introduces a new opportunity for error.

Don’t forget to bring all needed equipment (tape measures, personal protective equipment, smoke tubes, spare batteries, pens, paper, etc.); borrowing equipment from the customer (internal or external) also does not tend to enhance credibility and at many sites is not permitted.

Make arrangements in advance to safely access any difficult areas (e.g. using a scissor lift to reach areas on high ceilings).

Make arrangements in advance to drill needed holes in ductwork or make sure the needed holes are already in place when duct velocities will be measured.

Have an escort available to help insure safe operations, locate ventilation system on/off switches or baffles, properly operate ventilation systems, be able to describe actual in-use conditions, and more.

When performing ventilation surveys, be sure to note the position of baffles in the system to reflect actual in-use conditions and to red flag any possible concerns.

**Ventilation Surveys-Frequency**

A schedule should be developed for every ventilation system as specified in the applicable standard or, if not specified, based on formal risk assessment, taking into consideration appropriate factors, e.g. number of persons exposed, toxicity of chemicals controlled, potential for fire/explosion hazard and nature of any related equipment or operational capacity loss. It may be prudent not to exceed a periodic ventilation survey period of once every three years in the absence of any other guidance. Often it is helpful to place a calibration sticker on the equipment tested as a reminder of next ventilation survey due date and to help employees know when it is or is not safe to use a system.

Remember, things change—to quote a popular axiom, “the best laid plans of mice and men often go awry”. The previous section Sampling of Case Histories of Faulty Ventilation Systems should aptly illustrate this point.

**Documenting and Archiving Results**

Whatever format you choose to document your survey results, optimally all pertinent information is clearly documented to optimize the usefulness of the survey. It would be very wasteful to expend the time, expense and effort of performing ventilation surveys only to find the results rendered useless due to a failure to document all required information. To illustrate, the following is a partial list of pertinent information that should be collected (information may vary depending on the system):

- Make, model, type of ventilation system
- Agreed upon standard to be used for the ventilation survey
- Type of survey equipment used including make, model, serial number, last calibration date
• Atmospheric conditions, e.g. temperature, humidity, wind speed and direction if applicable, etc.
• Ventilation measurements
• System dimensional measurements
• Results of any smoke test
• Position of any system baffles, building bay doors, and other situations that could influence air flow
• Interviews of employees discussing use of the system
• A list of all air contaminants controlled by the system
• Location of the system in the facility so it can be easily identified for future surveys or repair purposes;
• List of any other pertinent survey observations, e.g. observation of damaged or missing system components, clogged filters, odd noises coming from ventilation systems, foreign material entrained in system components, etc.
• List of any other perceived relevant safety hazards observed even if unrelated to the actual ventilation survey.
• Conclusion of whether the survey indicates the appropriate standard is being met, and any recommendations.
• Recommendation for periodicity of system survey.

In the case of ventilation surveys, too much information tends to be better than not enough information. Photographing the system can also be very helpful when discussing any shortcomings related to system design with the customer.

When archiving information, archive the reports in an auditable fashion in a safe location with a clear indication of any purge date. Historically archive failures observed by this author have been all too common, including:

• Water and mold damaged records;
• Records subjected to annual “records purge parties” in order to “free up storage space;” and
• Records that presumably had been retained but could not be located.

Protecting Yourself from Injury
Unfortunately, sometimes we just “don’t know what we don’t know.” Truthfully, every one of us learns somewhat by trial and error, by mentoring, by tribal knowledge, and other informal methods. The best that can be said here is never rush, carefully follow all instructions provided, and beyond that engage in lifelong learning by reading, attending seminars, etc. to improve your knowledge of safe practices and potential pitfalls. Some examples are provided here to drive home the point of how very dangerous the survey process can be if we do not take necessary precautions:

• Wanting to finish the job no matter what. Example: boiling sodium hydroxide tank at electroplating facility that could not be safely approached for survey. It was very tempting to chance it; resist this temptation to avoid possible disaster.
• Battery rooms if when measuring ceilings tape measure falls onto the terminals of the battery or, particularly in tight quarters, if a long, metal thermal anemometer rod touches two terminals when measuring overhead ventilation in close proximity to batteries; this could
cause an explosion. As a precaution, I always try to have a third party serve as a spotter particularly since your focus is divided between your safety and the task at hand—not always easy.

- Failure to wear required PPE (personal protective equipment) or even know what PPE is required; example: staff receiving acid burns during survey.
- Failure to be aware of or follow required safety procedures. At one facility, it was required that all personnel working in the Hydrofluoric Acid (HF) area carry on their person calcium gluconate gel as a part of the immediate first-aid protocol for the prevention of hydrogen fluoride burns which can be severe and result in life-threatening complications (mode of action: HF actually removes calcium from the body).
- Using a survey instrument in various types of flammable, explosive or oxygen-deficient environments where the instrument does not have the appropriate rating; similarly, not having a multi-gas detector available to determine whether an area is safe to survey (and whether the survey instrument will function properly).
- Checking a perchloric acid hood that has not been properly maintained: explosive contaminants could be present within the system or within the hood.
- Exposing oneself to toxic constituents by failing to follow important safety instructions. One noteworthy example: TG17\textsuperscript{16} reads: All pre-fabricated storage buildings shall be equipped with adequate ventilation. The ventilation system shall be capable of providing at least 6 air changes per hour with an exhaust discharged vertically or in a location to prevent recirculation of the exhaust. The on/off switch for the ventilation system should be located outside the storage area (on the exterior of the building). A sign by the switch should read, “DO NOT ENTER UNLESS VENTILATION SYSTEM HAS OPERATED FOR AT LEAST TEN MINUTES.”
- Ergonomic injuries; e.g. sometimes it is best to place a vane anemometer on a telescoping stick for reaching distant areas to prevent injuries related to dynamic postures which are also static and repetitive.

\textbf{Protecting Integrity of Findings}

Best intentions and hard work can all be for naught if the work is invalidated, which can occur in a variety of ways. Here are a few pitfalls to be avoided:

- Working with survey equipment that has an expired annual calibration.
- Working with devices in conditions that exceed the capabilities of the instrument according to the manufacturer’s manual (humidity, temperature, oxygen deficiency, etc.)
- Not documenting pertinent conditions under which the survey is conducted, making it impossible to properly interpret survey results and provide meaningful conclusions and recommendations. For example: on vehicle garage maintenance surveys it is necessary to measure the face velocity at the end of a flexible hose; a single fan feeds many hoses, and each hose has a baffle that may be closed. What are the actual conditions when employees use the system? Open or closed baffles? Under what conditions did you sample? It may even be helpful to sample under varying conditions.

• Forgetting to identify the location of the source, particularly in locations where there may be multiple identical or similar sources—be sure to prepare a diagram showing the location of all sources, and assign each source a unique identifier if one is not already assigned. Otherwise, it may not be possible to assign survey results to the appropriate system.

• Welding: not finding out where the worker positions the hood while in use. The hood may be functioning within specifications but, if the worker is positioning the hood too far from the work surface, there could be issues.

• Misidentify type of system you are surveying and/or compare your results to specifications in the wrong standard.

• Gather insufficient data. One great example is the need to gather an appreciable amount of ancillary information relating to certain vehicle parameters when performing ventilation surveys on vehicle exhaust systems. Without that data a meaningful conclusion may not be gathered. A very helpful resource that provides much helpful information for these surveys and is available on the Internet is the Donaldson Engine Horsepower and Exhaust Flow Guide. A second example would be failure to collect all required measurements on an air contaminant source in order to be able look up the corresponding exhaust volume in an informational table. Case in point: 29 CFR 1926.57(g)(3)(vii) requires that grinding and polishing belts be provided with hoods to remove dust and dirt generated in operations and the hoods be connected to branch pipes having exhaust volumes as shown in Table D-57.6 of that standard (designated below as Table 1 for purposes of this paper). Notice how if there is a failure to measure the belt width at the time of the ventilation survey, there is no way to interpret the adequacy of the ventilation information collected.

<table>
<thead>
<tr>
<th>Belts width, inches (cm)</th>
<th>Exhaust volume (feet(3)/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 3 (7.62) .................</td>
<td>220</td>
</tr>
<tr>
<td>Over 3 to 5 (7.62 to 12.7) ....</td>
<td>300</td>
</tr>
<tr>
<td>Over 5 to 7 (12.7 to 17.78) ...</td>
<td>390</td>
</tr>
<tr>
<td>Over 7 to 9 (17.78 to 22.86) ...</td>
<td>500</td>
</tr>
<tr>
<td>Over 9 to 11 (22.86 to 27.94) ...</td>
<td>610</td>
</tr>
<tr>
<td>Over 11 to 13 (27.94 to 33.02) ...</td>
<td>740</td>
</tr>
</tbody>
</table>

Table 1. OSHA’s Required Exhaust Volumes for Grinding and Polishing Belts

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• Failing to collect survey data at the appropriate location. Example: paint booths. There are many varieties. For a drive in paint booth, do you measure the face velocity right at the filters; if so is that really providing an accurate picture of the potential exposures of the worker who works mostly in the middle third of a booth?
• Totally miss a LEV source. This is common with hidden employee jury-rigged LEV sources that a facility manager may be unaware of. Not unheard of are things like a hand-made system with a pipe and a collection dome over a sink faucet and overhead garage ventilation hoods used as ductwork into a home made wall-mounted exhaust bench for welding. Even if these are unconventional and there is no given standard to measure these to, it is helpful to characterize and survey against any applicable general guidelines and provide recommendations nonetheless.
• Failing to verify the lack of “dead spots” using smoke tests.
• Failing to sample a sufficient number of sample points to provide a proper characterization.
• Where it is necessary to measure duct velocity, using the wrong technique; most notably, improperly performing a “traverse” (measurements must be taken inside the duct in a very specific manner, but this author has seen measurements taken in a random manner and improperly interpreted).
• Totally overlooking an air supply or air exhaust during the survey (there can be multiple supplies and exhausts for a given system and some may not be as readily visible as others).

Preventing Survey Equipment Damage
Survey equipment may be very delicate and easily subject to damage; it may also be very costly to repair or replace. Also when you are in the field, loss of functionality of a piece of survey equipment can quickly terminate the survey.

• Check equipment thoroughly upon receipt and immediately report any problems. Plan to have a plan “B” if at all possible; research any local equipment rental vendors in the location where you will be working just in case.
• Do not degrade equipment performance by damaging or destroying equipment through improper use; i.e., using a delicate thermal anemometer with a very thin heated wire element in a highly corrosive environment
• Drop it and bend or break delicate components
• Kink any cords (easily bent when closing the instrument case if not careful)
• Carry instrument around in hand on site vs. carrying in the case to keep it safe
• Pack properly for shipping
• Mail equipment via a traceable, insured method (can be lost or damaged in transit)
• Remove batteries before storage to prevent corrosion from leaking battery acid.

Summary
If ventilation systems used for the control of hazardous air contaminants are not properly designed, used, and maintained, properly performed ventilation surveys performed by a competent individual may be the only means for identifying and correcting these concerns so that system effectiveness may be restored. Otherwise, systems may not control air contaminant, fire, and/or explosion hazards, and in fact may exacerbate exposures to hazards by providing management and workers with a false sense of security. Optimal ventilation survey technique combined with system owner/operator education is paramount in insuring worker, facility, and
operations protection where these systems are installed and relied upon. What you, as either a manager, worker, Safety professional or Industrial Hygiene professional don’t know about ventilation surveys can hurt you in terms of chronic worker overexposure to air contaminants, lost productivity, liability, facility damage, and interruption of operations. Make sure that your air contaminant ventilation systems are scheduled for routine ventilation surveys performed by a competent individual.