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VENTILATION TECHNICAL GUIDE, 2nd Edition

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Due to the lack of clear regulatory or Air Force guidance regarding the frequency of performing ventilation surveillance, many base-level bioenvironmental engineering elements and flights have ventilation programs that are not in compliance. As a response to an Air Force Audit Agency audit, this report was created to provide the base-level bioenvironmental engineering elements and flights with recommended program management practices and a recommended method for performing health-risk assessments to establish a baseline survey. Properly established baseline surveys are critical for ensuring the health and safety of the worker. The Ventilation Technical Guide recommends program guidance for executing a ventilation program with active oversight of the program to prevent deficiencies from occurring. Additionally, the report provides a recommended method for determining frequency of surveillance based on the exposure to the worker using air sampling data and statistics. Lastly, it contains reference materials for determining design criteria for specific operations.

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EXECUTIVE SUMMARY

The abrasive blasting cabinet section located in Appendix A of this guide has been updated significantly and now contains the recommended baseline evaluation criteria for the ventilation system, along with recommendations for how frequent to collect periodic ventilation measurements. The previous version of this technical guide considered the cabinet as the sole engineering control, but this has been revised to include the ventilation system as part of the engineering control system.

The Ventilation Technical Guide is designed to assist in both the management and execution of ventilation programs across the Air Force.

This guide covers the recommended roles and responsibilities for executing a ventilation program with active program oversight to prevent deficiencies from occurring. It also recommends annual program reviews to ensure completion of all surveys.

Ventilation surveillance is used throughout the Air Force to control occupational and environmental health hazards as an engineering control. Ventilation is primarily used to prevent exposures to workers via inhalation and to control the buildup of analytes and particulates that can create an explosion hazard. The key to illness and injury prevention is monitoring the ventilation system for performance metrics (static pressure, velocity pressure, and volumetric flow rate) that indicate the atmosphere is a safe work environment.

This guide provides a recommended method for conducting surveillance based on determining the exposure to the worker using air sampling data and statistics.

Within this document, the U.S. Air Force School of Aerospace Medicine details the following for determining ventilation surveillance compliance:

- Suggested program guidance
- Useful calculations
- How to conduct a health-risk assessment
- How to establish a ventilation baseline

There are three appendices to supplement the content of information in the technical guide. Appendix A contains an in-depth description of a variety of operations where ventilation is used to control hazardous exposures to the worker. Appendix B contains a recommended diagram for establishing a baseline. Appendix C contains the cited references and a comprehensive list of ventilation references from regulatory agencies, the U.S. Air Force, and other relevant sources.

The U.S. Air Force School of Aerospace Medicine Environmental Safety and Occupational Health Service Center is available to answer any further technical questions at DSN 798-3764 or by email at esoh.service.center@wpafb.af.mil.

CHANGES FROM THE VENTILATION TECHNICAL GUIDE, 1ST EDITION

Changes include significant updates to the abrasive blasting cabinet section located in Appendix A, which now contains the recommended baseline evaluation criteria for the ventilation system, along with recommendations for how frequently to collect periodic ventilation measurements. The previous version of this technical guide considered the cabinet as the sole engineering control, but this is now revised to include the ventilation system as part of the engineering control system.

VENTILATION TECHNICAL GUIDE

1.0 Background. This guide was developed in response to an Air Force Audit Agency Corrosion Control Audit Report, which indicated a lack of uniformity by bioenvironmental engineering flights when performing ventilation surveys across the Air Force. Since Air Force Occupational Safety and Health (AFOSH) Standard (STD) 161-2, *Industrial Ventilation,* was rescinded, there has been a lack of clear guidance on how to properly conduct ventilation surveillance. The U.S. Air Force School of Aerospace Medicine (USAFSAM) was tasked to create a technical guide that provides the "back-to-basics" knowledge regarding the proper execution of a ventilation program at base level.

1.1. The intent of this guide is to address the project management requirements for bioenvironmental engineering (BE) flight commanders or element leaders who are ultimately responsible for the ventilation program. Additionally, the guide will provide program execution assistance through recommended guidance for the technicians who conduct the program.

1.2. This guide assumes the user has attended either the BE Officer Course or the BE Apprentice Course and has a basic understanding of how and why to monitor a ventilation system. This guide is intended to meet the additional requirement of being comprehensible by any 7-level BE technician.

2.0 Recommended References and Abilities. It is highly recommended that every BE flight and element obtain several references to aid them in managing and executing a ventilation program. The American Conference of Governmental Industrial Hygienists (ACGIH) industrial ventilation design manual contains the fundamental equations for calculating ventilation parameters such as capture velocity, density factors, etc. It also has a section for "specific operations" that specifies volumetric flow rate, minimum duct velocity, and hood entry losses for a wide range of base-level operations. The ACGIH industrial ventilation operation and maintenance manual describes the fundamentals of measuring techniques used to collect ventilation data, troubleshooting, and strategies for determining frequency of surveillance. The American Industrial Hygiene Association (AIHA) Strategy for Assessing and Managing Occupational Exposures Manual is useful for completing a health-risk assessment to determine the frequency of surveillance based on the collection of air sampling data.

2.1. Recommended Reference List.

- ACGIH, "Industrial Ventilation: A Manual of Recommended Practice for Design"
- ACGIH, "Industrial Ventilation: A Manual of Recommended Practice for Operation and Maintenance"

- AIHA, "A Strategy for Assessing and Managing Occupational Exposures"

2.2. Recommended Abilities. To properly execute a ventilation program, the BE flight needs the following abilities:

- The ability to measure static pressure and velocity pressure in a duct
- The ability to measure the intake and exhaust flow rates inside an office building
- The ability to measure face velocity in a hood or at the front of a filter or local exhaust

If there are deficiencies in any of these areas, it is recommended that the individual review his/her technical school material (BE officer/apprentices notes), career development courses, or the list of references above to correct the deficiency. Routine use and training of the ventilation equipment are keys to maintaining proficiency in the ventilation system monitoring.

3.0 Suggested Program Guidance. To set expectations for those who perform ventilation program management and collect ventilation measurements, a review of the Course Training Standard (CTS) for BE officers and the Career Field Education and Training Plan (CFETP) for enlisted members is discussed below (Ref 1) [BE Officer BE200 (Full Course), Course Training Standard, 14 Sep 2010; contact USAFSAM's BE Force Development Division (OED) for a copy of this document].

3.1. According to the CTS, a 43E1X has the following abilities listed in Tables 1 and 2 below with respect to working with mechanical ventilation systems. In general, the following statement summarizes the subject knowledge levels of the 43E1X: "they can identify relationships of the basic facts and state the general principles about the subject." The task knowledge can be summarized as "they can accurately describe the steps necessary to complete the task at hand." Finally, for their task performance level, "they can do most parts of the task and only need assistance on the most difficult parts" [BE Officer BE200 (Full Course), Course Training Standard, 14 Sep 2010; contact USAFSAM/OED for a copy of this document].

Table 1. 43E1X CTS Ventilation Task Proficiency Codes

Course Training Standard Requirements	Proficiency Code
2.8 Mechanical Ventilation Systems	
2.8.1 Types of Pressure	B
2.8.2 Pressure Losses	B
2.8.3 Velocity	B
2.8.4 Mass Flow	B
2.8.5 Ventilation System Design Review (Design Criteria)	B
2.8.6 Principles of Dilution Ventilation	B
2.8.7 Principles of Local Exhaust Ventilation	B
2.8.8 Types of Hoods	B
2.8.9 System Advantages and Disadvantages	B
2.8.10 Ventilation Survey Requirements (Initial, Baseline, and Routine)	B
2.8.11 Perform Ventilation Calculations	2b
2.8.12 Perform Face Velocity Ventilation Survey	2b
2.8.13 Perform Capture Velocity Survey	2b
2.8.14 Perform Pitot Traverse Ventilation Survey	2b
2.8.15 Perform Static Pressure Measurements	2b
2.8.16 Follow-Up Actions for Deficient Ventilation Systems	B

Table 2. Qualitative Requirements for the CTS and CFETP

Proficiency Code Key	
Scale Value	**Definition: The Individual**
	Task Performance Levels
1	Can do simple parts of the task. Needs to be told or shown how to do most of the task. **(Extremely Limited)**
2	Can do most parts of the task. Needs only help on hardest parts. **(Partially Proficient)**
3	Can do all parts of the task. Needs only a spot check of completed work. **(Competent)**
4	Can do the complete task quickly and accurately. Can tell or show others how to do the task. **(Highly Proficient)**
	Task Knowledge Levels
a	Can name parts, tools, and simple facts about the task. **(Nomenclature)**
b	Can determine step-by-step procedures for doing the task. **(Procedures)**
c	Can identify why and when the task must be done and why each step is needed. (**Operating Principles**)
d	Can predict, isolate, and resolve problems about the task. **(Advanced Theory)**
	Subject Knowledge Levels
A	Can identify basic facts and terms about the subject. **(Facts)**
B	Can identify relationship of basic facts and state general principles about the subject. **(Principles)**
C	Can analyze facts and principles and draw conclusions about the subject. **(Analysis)**
D	Can evaluate conditions and make proper decisions about the subject. **(Evaluation)**

3.2. Per the enlisted BE CFETP, a technician's ability to perform ventilation surveillance activities is tied to the individual skill level. For ventilation-specific abilities, Table 3 below lists the abilities for a three-, five-, and seven-level trained technician (Ref 1), while Table 2 provides the definitions for the ratings found in Table 3.

3.2.1. A 3-level BE technician has the following capabilities regarding subject knowledge levels, task knowledge, and performance: The individual can identify basic facts and terms about the subject with the exception of ventilation design reviews. The individual is capable of determining the steps involved in completing a task and can complete most parts of a task by themselves, with assistance needed only during the most difficult part of the task (Ref 1).

3.2.2. A 5-level (Career Development Course completed) BE technician has the following capabilities regarding subject knowledge levels and task knowledge. In addition to the 3-level capabilities, this individual can identify relationships of the basic facts and state the general principles regarding the subject. This applies to the ventilation system design review process that was not a previous capability for the 3-level technician. The individual is also capable of determining the step-by-step procedures for completing the task (Ref 1).

3.2.3. A 5-level [on-the-job training (OJT) completed] BE technician has the following capabilities regarding subject knowledge levels, task knowledge, and performance: In addition to the 3-level capabilities, individuals can complete all parts of a task; however, they do require "spot checks" of their completed work (Ref 1).

Table 3. Enlisted BE CFETP Ventilation Task Proficiency Codes

Tasks, Knowledge, and Technical References	Core	Proficiency Codes (see Table 2) Indicate Required Training Level[a]			
		3-lvl Course	5-lvl OJT	5-lvl CDC[b]	7-lvl Course
4.13 Mechanical Ventilation Systems					
4.13.1 Types of pressure		A	-	B	-
4.13.2 Pressure losses		A	-	B	-
4.13.3 Velocity		A	-	B	-
4.13.4 Mass flow		A	-	B	-
4.13.5 Ventilation system design reviews		-	-	B	-
4.13.6 Principles of dilution ventilation		A	-	B	B
4.13.7 Principles of local exhaust ventilation		A	-	B	B
4.13.8 Types of hoods		A	-	B	-
4.13.9 System advantages and disadvantages		A	-	B	-
4.13.10 Ventilation survey requirements (initial, baseline, routine)		A	-	B	C
4.13.11 Perform ventilation calculation	5	2b	3c	b	-
4.13.12 Perform face velocity ventilation survey	5	2b	3c	b	-
4.13.13 Perform capture velocity survey	5	2b	3c	b	-
4.13.14 Perform pitot traverse ventilation survey	5	2b	3c	b	-
4.13.15 Perform static pressure checks	5	2b	3c	b	-
4.13.16 Follow-up actions for deficient ventilation systems		A	-	B	-

[a]7-lvl OJT & Advanced Course have no required training level.
[b]CDC = Career Development Course.

3.2.4. A 7-level BE technician has the following capabilities regarding subject knowledge levels, task knowledge, and performance: In addition to the previous skill levels capabilities, the individual can analyze facts and principles of the subject and can draw conclusions pertaining to initial, baseline, and routine ventilation survey requirements (Ref 1).

4.0 Determining Ventilation Systems that Require Monitoring. It is important to survey the base for existing systems to ensure all ventilation systems controlling occupational hazards are included in the program. If a ventilation system is identified and requires monitoring, then it needs to be documented in the Defense Occupational Environmental and Health Readiness System (DOEHRS). Following established guidance, DOEHRS must be used to document all changes to the system. For instance, if the system is taken off-line for maintenance or if the process changes, then DOEHRS must be used to document the changes.

5.0 Ventilation Design Review. For ventilation design review, there are two basic types of ventilation systems: heating, ventilation, and air conditioning (HVAC) and industrial. For an HVAC system, the BE should be concerned with maintaining the appropriate number of air changes per hour, as well as maintaining a comfortable temperature and humidity range throughout the year. If the building HVAC is adequate based upon the size of the room and the number of occupants, it will ensure the building will be less likely to have mold problems, carbon dioxide buildup issues, etc. If, however, the ventilation system being proposed is an industrial system, the BE will need to ensure the building designers have included an adequate ventilation system that is capable of controlling exposures to the worker. A design review for an industrial ventilation system should prompt the BE to ask the question, "Why?" What is the need? What design criteria were used to determine that the system will be able to control the hazard once the process is in operation? What assumptions were used to determine the adequacy of the selected system?

Asking these questions will help ensure the proposed industrial ventilation system has been properly designed and will need minimal adjustments once put into operation.

6.0 Determining Surveillance Frequency. After determining the need for monitoring, the next step in the process is to determine the monitoring frequency requirements for each individual ventilation system. For example, the monitoring frequency could be quarterly, semi-annually, annually, or other locally determined frequency. To determine the monitoring frequency, the technician must first determine if the hazard has requirements specified by a regulatory authority, such as the Occupational Safety and Health Administration (OSHA). In addition, Appendix A provides information on various dilution and local exhaust ventilation systems.

6.1. From a review of all current (2011) OSHA expanded standards, only lead has a mandated survey frequency of at least one survey per quarter (Ref 2). For all other OSHA expanded standard chemicals, the recommendation is to use professional judgment when determining the frequency of surveillance. OSHA suggests "the static pressure drop at the exhaust ducts leading from the equipment shall be checked when the installation is completed and ***periodically*** thereafter to assure [*sic*] continued satisfactory operation" (Ref 3). Additionally, OSHA states that "when ventilation is used to control exposure, measurements that demonstrate the effectiveness of the system in controlling exposure, such as capture velocity, duct velocity, or static pressure shall be made as necessary to maintain its effectiveness" (Ref 4). The definition of "periodic," according to American National Standards Institute (ANSI), is as follows, "performing a task at a time interval suitable for maintaining the system or equipment in acceptable working condition and that will not cause deterioration of emission or employee exposure control" (Ref 5). Finally, Air Force Instruction (AFI) 48-145, *Occupational and Environmental Health Program*, section 4.3.4.2, states "perform periodic control evaluations" and leaves the decision of the frequency to be determined locally (Ref 6).

6.2. A baseline survey for a ventilation system is the combination of collecting ventilation data in the form of volumetric flow rate, static pressure, and velocity pressure along with air sampling data to ensure exposures to the worker are acceptable. When establishing a baseline for a ventilation system, the ventilation survey frequency should be based on a combination of professional judgment and accepted practices, mathematical modeling (depending on the physical state of the hazard), and air sampling data to gain confidence in the characterization and control. The following ventilation frequency recommendations are based on the flowchart in Appendix B.

6.3. In general, ventilation systems controlling exposure to OSHA expanded standard chemicals should be initially monitored on a quarterly basis. Furthermore, if air sampling results indicate that exposures are at or above the action level, then quarterly monitoring is recommended. The action level, by definition, is one-half of the occupational and environmental exposure limit (OEEL).

6.4. Semi-annual surveillance is recommended for medical ventilation systems per AFI 44-108, *Infection Control Program*, and for other industrial operations where air sampling or mathematical modeling has shown that the exposure to the worker is greater than $1/10^{th}$ of the OEEL but less than 1/2 of the OEEL.

6.5. Annual ventilation surveys are appropriate for processes where exposures are less than $1/10^{th}$ of the OEEL as is frequently seen in woodworking processes and engine exhaust control systems (Ref 6).

6.6. The above recommendations are applicable for ventilation systems for which little or no data exist. Monitoring frequency can be adjusted as more data become available to better characterize the hazard, potential exposure, and overall health risk. Some ventilation systems may never have enough air sampling data to use this methodology, for example, entomology mixing slot hoods, where very few OEELs exist; auto hobby shop paint booths, which have many users and types of paints; battery charging rooms; lab hoods; and fully enclosed milling/lathes where the operator is physically separated from the process. Appendix A provides some information on these types of ventilation systems.

7.0 Ventilation Design Criteria versus Ventilation Baseline Criteria. A common error found in base-level ventilation programs across the Air Force is not applying the appropriate standard for comparison when collecting ventilation data. Frequently, design criteria are used without establishing a proper baseline. A baseline survey consists of ventilation measurements (static pressure, velocity pressure, and volumetric flow rate) and air sampling. Design standards are theoretical calculations used for determining how the ventilation system should operate in the absence of confirmatory air sampling. The values for minimum airflow rates, duct velocity rates, and hood entry losses are found in the design version of the ACGIH ventilation manual. Obviously, there will be differences between the theoretical calculations and the actual operation when the system is operational. Once a baseline survey is completed, the exposure to the worker, as determined by air sampling, can be linked to the ventilation system through the performance metrics (static pressure, velocity pressure, and volumetric flow rate) of the system. To determine whether a system is in compliance or not, technicians should compare future ventilation surveys to the baseline criteria, not design criteria.

7.1. After the system is installed, an acceptance survey will be completed, most likely by a contractor, to demonstrate that the system operates within the required specifications. The measurements obtained during the acceptance survey may or may not become the baseline values for future surveys. In other words, if air sampling is conducted soon after the acceptance survey and the hazard is controlled to an acceptable level, there is no need to make further adjustments to the ventilation system.

7.2. The baseline values are the values the ventilation program manager will use to compare all future ventilation monitoring results to for compliance purposes. The purpose of most ventilation systems is to control hazardous exposures to workers. Contaminants that are generated need to be measured while the ventilation system is operating to ensure the workers' exposure is acceptable. This quantitative assessment is accomplished by conducting air sampling along with ventilation measurements and is part of the health risk assessment compliance requirement.

8.0 Establishing a Ventilation Baseline. The first step in establishing a baseline for a ventilation system is to collect a statistically significant amount of air samples. It is the tying together of the volumetric flow rates, face velocities, and static pressure measurements with acceptable exposure measurements that allows one to conclude that the hazard is being controlled. Appendix B contains a flowchart that outlines the steps that will be discussed below.

8.1. When determining a sampling strategy, it is highly recommended to review chapter 6 in the AIHA publication *A Strategy for Assessing and Managing Occupational Exposures*. This chapter explains the rationale for the number of samples that needs to be collected to minimize the estimation of variance for air sampling results. AIHA's recommendation is to randomize the air sampling obtained by varying the workers sampled, the time of day when a sample is collected, and even sampling during different seasons. All of the statistical assumptions are based on random air sampling, as this is an essential condition for using this method (Ref 7).

8.2. To minimize the upper confidence limit with respect to the estimate of variance, it is recommended that at least six air samples be collected depending on the results of the first air sampling effort. If the initial air sampling results (three samples) are <10% of the OEEL or greater than the OEEL, then fewer than six measurements can be used to make a decision. AIHA recommends collecting at least six samples when the initial results fall in-between the above-stated results. If the results of air sampling are greater than the action level or the OEEL, then either adjust the ventilation system to better capture the contaminant or modify the work process if it is not optimal for collecting the contaminant (Ref 7).

8.3. To have a high degree of confidence in characterization, the number of air samples taken will need to be statistically significant, but given the difficulties in obtaining air sampling data, it is advisable that three to six samples be collected. This technical guide will not address air sampling strategies, but highly recommends using the AIHA exposure control rating categorization presented in *A Strategy for Assessing and Managing Occupational Exposures*, pages 258-259. The control rating categories are below in Table 4 and can be used to help determine the frequency of ventilation surveys based on air sampling results. The exposure control ratings range from 0 to 4 with associated ranges of the estimated exposure concentration (Ref 7).

Table 4. Exposure Control Rating Table

Exposure Control Ratings	Cutoff (%OEEL)	Confidence Level
0	$X_{0.95} \leq 1\%$	High
1	$1\% < X_{0.95} \leq 10\%$	
2	$10\% < X_{0.95} \leq 50\%$	Medium
3	$50\% < X_{0.95} \leq 100\%$	Low
4	$X_{0.95} > 100\%$	

8.4. After collecting the air sampling data, insert the results into DOEHRS. Use the "IHSTAT" spreadsheet that comes with the book or create your own spreadsheet to analyze the data. The spreadsheet will automatically calculate a variety of statistical measurements that are useful for analyzing exposures to the worker. After entering the data into the spreadsheet, find the result for the "95th Percentile" under the "Lognormal Parametric Statistics" on the spreadsheet (highlighted in yellow). The example below in Figure 1 has results of four samples collected from a process with an OEEL of 100 ppm. The results for the 95th percentile are 41 ppm; therefore, this process is designated an Exposure Control Rating of 2 (Ref 7).

Industrial Hygiene Statistics		
Data Description:		
OEL	**DESCRIPTIVE STATISTICS**	
100	Number of samples (n)	4
	Maximum (max)	24
Sample Data	Minimum (min)	8
(max n = 50)	Range	16
No less-than (<)	Percent above OEL (%>OEL)	0.000
or greater-than (>)	Mean	14.750
15	Median	13.500
8	Standard deviation (s)	6.801
12	Mean of logtransformed data (LN)	2.613
24	Std. deviation of logtransformed data (LN)	0.458
	Geometric mean (GM)	13.635
	Geometric standard deviation (GSD)	1.581
	TEST FOR DISTRIBUTION FIT	
	W-test of logtransformed data (LN)	0.998
	Lognormal (a = 0.05)?	Yes
	W-test of data	0.953
	Normal (a = 0.05)?	Yes
	LOGNORMAL PARAMETRIC STATISTICS	
	Estimated Arithmetic Mean - MVUE	14.733
	$LCL_{1,95\%}$ - Land's "Exact"	9.919
	$UCL_{1,95\%}$ - Land's "Exact"	38.023
	95th Percentile	**28.965**
	$UTL_{95\%,95\%}$	143.919

Figure 1. Statistical Output from IHSTAT

8.5. If the rating is 0 or 1, then it is recommended to perform annual ventilation surveys. If the rating is 2, then it is recommend to perform semi-annual surveillance. If the rating is 3, then quarterly surveillance is recommended. Lastly, if the rating is 4, then action should be taken to reduce exposures using administrative controls until the ventilation system is adjusted to reduce the exposure to a level below the OEEL (Ref 7).

9.0 Measurement Techniques. Ventilation measurement techniques are contained in Appendix C of *Industrial Ventilation: A Manual of Recommended Practice for Design* and more thoroughly in Chapter 3 of *Industrial Ventilation: A Manual of Recommended Practice for Operation and Maintenance*. The latter has a more thorough review of ventilation measurement techniques than the design manual, as well as a wealth of information regarding the testing and measurement of ventilation systems. Specific instructions for collecting duct velocities and face velocities will not be discussed, since this information is covered in the Career Development Courses and BE officer and apprentice courses with the exception of a best practice explained below.

9.1. When collecting face velocity measurements, a "best practice" is to use a tripod (if possible, depending on the height of the duct) to hold the anemometer in each location and avoid blocking the flow of air into the area where these measurements are being collected (Ref 8).

10.0 Ventilation System Operation and Maintenance. It is recommended that the ventilation program manager review the ACGIH operation and maintenance manual, Chapter 3, "Testing and Measurement of Ventilation Systems," which describes how to properly measure ventilation systems, and Chapter 7, "Troubleshooting Ventilation Systems," for an explanation on what to do in the event the survey results are outside the acceptable range of values. The following discussion will reference specific page numbers in this manual to assist the user in quickly finding the needed information.

10.1. To begin, it is important to know what the standard temperature, pressure, and moisture conditions are for all ventilation calculations. The standard assumption is an altitude of 0 ft, a temperature of 70 °F, and atmospheric pressure of 407 inches water gauge ("wg) or 1 atm. If these are not the environmental conditions at your base, then you may need to account for the difference since it may significantly affect the determination of volumetric flow rate. Density factors (df) are used to account for the variance in environmental conditions that would result in either an increase or decrease of volumetric flow rate in the ventilation system. If the actual conditions in the system are standard temperature and pressure, then the df for each is equal to 1. If your base has a significantly higher temperature, air moisture content, duct static pressure, or elevation conditions, then use the density factor equation shown below in Equation 1 to account for environmental factors that are not standard (Ref 9):

$$df = (dfe)(dft)(dfp)(dfm) \tag{1}$$

dfe = elevation density factor
dft = temperature density factor
dfp = duct pressure density factor
dfm = moisture density factor

10.2. In previous editions of the ACGIH design ventilation manual, they advised that the density factor should not be taken into account until the temperature in the work area is > 100 °F, or the dew point is > 80 °F, or the shop is located at an elevation > 1000 feet above sea level, or a duct static pressure is > -20 "wg. Each of these variances represents a 5% effect on the air volume. (Ref 9).

10.3. However, this has been revised in the 27th edition of the ACGIH design ventilation manual. Page 3-15 states that the density factor should be used often to account for all changes in air density. The exceptions are in the case of no heat or moisture added to the system, shop location near sea level, and a system static pressure (SSP) of < 12 "wg (Ref 9). For all other cases, use the elevation, temperature, and duct pressure density factors in Equations 2, 3, and 4 below.

10.4. The density factors for temperature and elevation are straightforward to obtain. The temperature can be measured directly with an instrument of the technician's choosing. The elevation can be obtained from an Internet search on the location.

$$dfe = [1-(6.73x10^{-6})(z)]^{5.25} \quad (2)$$

z = elevation in feet (ft)

$$dft = (530)/(T + 460) \quad (3)$$

T = temperature in degrees Fahrenheit (°F)

10.5. The duct pressure density factor in contrast is much more difficult to obtain due to multiple measurements needing to be collected in multiple locations of the ventilation system (Ref 9). To determine SSP, use Equation 5 below and measure static pressure and velocity pressure just prior to the fan to obtain the SP_{in} and VP_{in} values. SP_{out} can be measured after the fan to determine if the static pressure density factor should be used to adjust the velocity equation. If it is not practical to measure static and velocity pressure at these points in the system, then leave this density factor out of the density factor equation, but remember that this could be significant in the calculations (Ref 8).

$$dfp = (407 + SSP)/(407) \quad (4)$$

SSP = system static pressure ("wg)

$$SSP = SP_{out} - SP_{in} - VP_{in} \quad (5)$$

SP_{out} = static pressure after the fan

SP_{in} = static pressure just prior to the fan

VP_{in} = velocity pressure just prior to the fan

10.6. The moisture density factor equation is by far the most complicated of all and is explained in detail because of this reason. To calculate the moisture density factor, the first step is to measure the wet bulb temperature. Take this number and turn to page 9-53 of the “Design” version of the ACGIH industrial ventilation manual 27th edition or see Figure 2 below. Find the psychrometric chart and use it to determine the pound mass of water per pound mass of dry air. On the left side of the graph find the wet bulb temperature in the “Wet Bulb, Dew Point & Saturation Temperatures - °F” (Ref 9).

10.6.1. Next, find the dry bulb temperature at the bottom of the chart and find where these two lines intersect. Then follow the point of intersection to the right to obtain the moisture content in units of grains per pound of dry air. Use the conversion for grains to pounds, 1 grain = 1.428×10^{-4} pounds, to convert to pound mass of water (lbm water) per pound mass of dry air (lbm dry air). An example is provided in Figure 2 below where the wet bulb temperature is 55 °F and the dry bulb temperature measures 75 °F. Follow the red arrows to the point where the lines intersect and then follow the red arrow to the right to determine the moisture content, which in this case is 33 grains per pound of dry air. Use the conversion above to determine omega (ω), and the result is 0.0047 lbm water/lbm dry air. Plug ω into the moisture density factor in Equation 6 below (Ref 9).

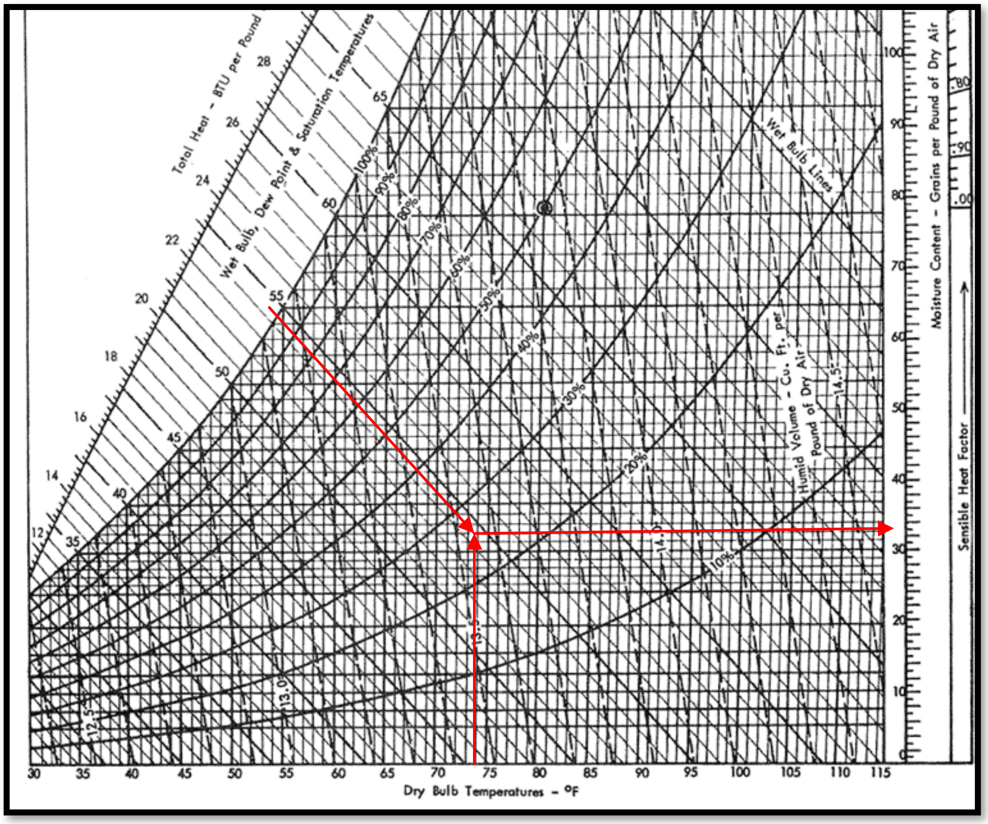


Figure 2. Psychrometric Chart (Ref 9)

$$dfm = (1+\omega)/(1+1.607\omega) \qquad (6)$$

ω = absolute moisture (lbm water/lbm dry air)

10.7. To calculate the volumetric flow rate, obtain face velocity measurements and use Equation 7. To determine the velocity inside the duct when performing pitot-traverse, convert all velocity pressure measurements to velocities then to average velocities using Equation 8 (Ref 9).

$$Q = VA \qquad (7)$$

Where: Q = Volumetric flow rate (ft^3)
V = Velocity (ft/min)
A = Area (ft^2)

$$V = 4005\sqrt{\frac{VP}{df}} \qquad (8)$$

Where: V = Velocity (ft/min)
VP = Velocity Pressure ("wg)
df = density factor (unitless)

10.8. Once the pitot traverse method has been used to estimate the volumetric flow rate and as long as the system does not change through the addition or removal of hoods, etc., then Equation 9 can be used to calculate the new volumetric flow rate utilizing previous and current static pressure and density factor measurements (Ref 9):

$$Q_1 = Q_2 \sqrt{\frac{SP_1/df_1}{SP_2/df_2}} \qquad (9)$$

Solving Equation 9 for Q_2 we arrive at Equation 10 below:

$$Q_2 = \frac{Q_1}{\sqrt{\frac{SP_1/df_1}{SP_2/df_2}}} \qquad (10)$$

10.9. Using the volumetric flow rate (Q_1), static pressure (SP_1), and density factor (df_1) from the previous sampling event, the technician can calculate the volumetric flow rate (Q_2) using Equation 10 for the current sampling event using the static pressure measurement (SP_2) and calculating the density factor (df_2) for the current quarter. If the air density is not expected to change over time, then Equation 10 simplifies to Equation 11 below (Ref 9):

$$Q_2 = \frac{Q_1}{\sqrt{\frac{SP_1}{SP_2}}} \qquad (11)$$

This equation should significantly reduce the amount of time for a technician to determine volumetric flow rate in a duct.

10.10. The location where static pressure and velocity pressure are measured is an important consideration. See Figure 3 below for a visual representation of useful locations to collect measurements taken from page 14-36 of the ACGIH design ventilation manual. In general, use face velocity measurements for hoods or open filters and pitot traverse measurements to measure static pressure and velocity pressure at strategic locations in the system to detect system degradation. For velocity pressure measurements, the general rule of thumb is to measure four to six duct diameters upstream from a bend or branch in the system and two to three duct diameters downstream before another bend or branch in the system. Measurement locations are represented as points “a” and “b” on branch “A” and “B” in Figure 3 shown below (Ref 9).

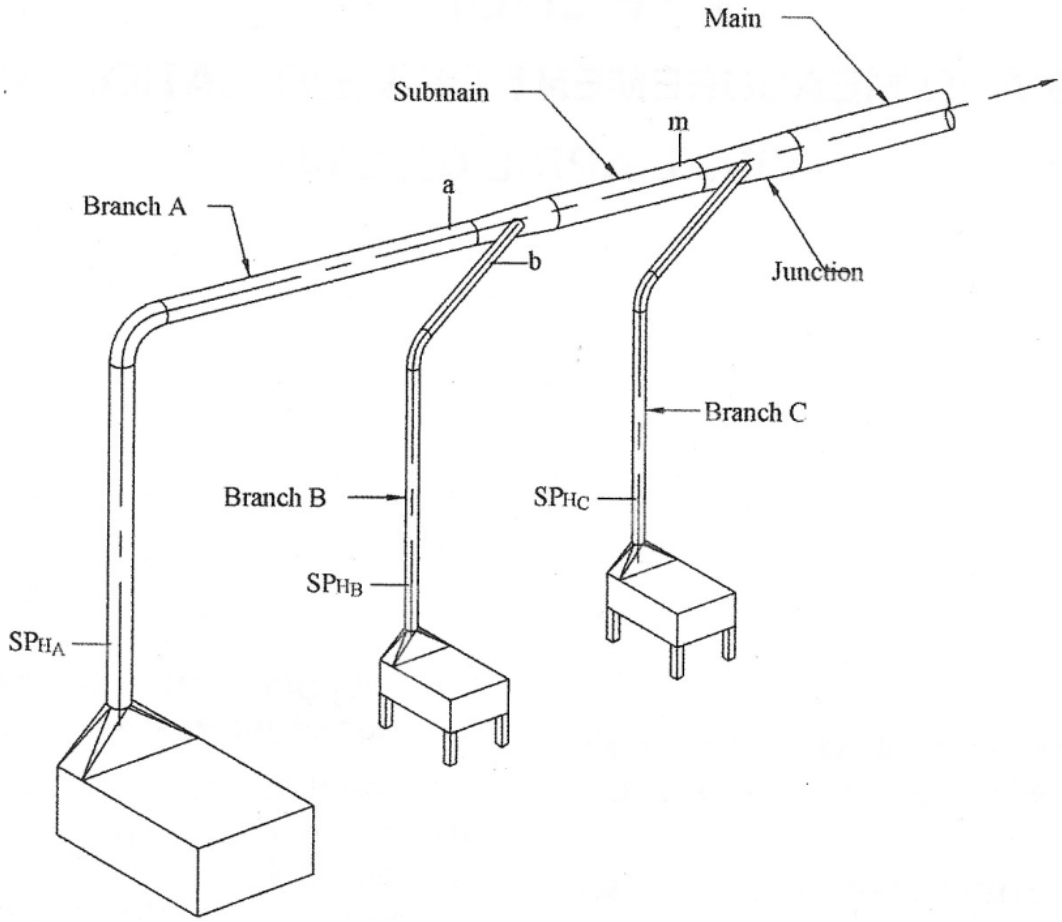


Figure 3. Locations for Collecting Ventilation Measurements (Ref 9)

11.0 Suggested Measurement Criteria. After collecting a series of pitot traverse measurements in a duct or face velocity measurements in a hood, how does the technician know if the results of these measurements are acceptable or not? Obviously, by comparing the results to the baseline measurements, but since the likelihood of the numbers being the same is very low, how much variability in the system is acceptable? The ventilation system will have variability associated with its operation based on a variety of environmental conditions. The instrumentation used has its own variability, which can be minimized or magnified by the expertise of the technician collecting the sample.

11.1. According to the ACGIH operation and maintenance manual on page 5-9, a system that has static pressure measurements ± 20% of the baseline values is an indication that the system is starting to develop problems. For volumetric flow rate measurements, the criterion is ± 10% of the baseline values. These values are not set in stone and may need to be adjusted based on professional judgment, which should be based on air sampling data to back up the decision to adjust these values. It is important to stay within the established criteria for several reasons. If the flow rate is too low, then the hood is not adequately capturing the contaminants generated in the worker's breathing zone. If the flow rate is too high, then we are pulling volumetric flow rate from other hoods located in the ventilation system, which causes lower volumetric flow rates in those hoods. Additionally, we are wasting energy and increasing maintenance costs by having the fan operate at a higher than optimal rate. Finally, depending on the contaminant being captured, higher than optimal flow rates will increase the degradation rate of the ventilation system (Ref 8).

11.2. If baseline data have not been collected, refer to the ACGIH industrial ventilation design book (specifically Chapter 13) to determine what the face velocity and duct flow rate should be per design criteria. Then, collect the appropriate samples from appropriate points in the system to establish a baseline for future comparison. Air sampling will also need to be accomplished to ensure the system is controlling the hazard.

12.0 Troubleshooting Ventilation Systems. Degradation of a ventilation system is inevitable. Even with regularly scheduled maintenance, a ventilation system can degrade to the point where the system is no longer operating within the established parameters for static pressure and volumetric flow rate variability. When a quarterly, semi-annual, or annual ventilation survey results in an unsatisfactory flow rate (greater than ± 10%) or static pressure (greater than ± 20%), the BE should try to figure out not only why this is occurring but specifically where the problem could be located in the system. The ownership for maintenance of a ventilation system belongs to Civil Engineering for all buildings outside of the Medical Group and to Facilities Management within the Medical Group. Ultimately, it is their responsibility to maintain and balance the ventilation system as necessary, but the BE can assist in identifying issues through regular surveillance (Ref 8).

12.1. The process for resolving a problem with a ventilation system begins with a conversation with the shop workers or the shop supervisor. It is important to determine if anything has changed with the ventilation system since the last survey. Has the regularly scheduled maintenance occurred? Is preventative maintenance occurring at all? Have there been any branches added or have any of the branches been removed? Have workers blocked off portions of the duct system? Has there been any recent damage to the duct system? Depending on the answers you receive from the questions you ask, the BE should be able to narrow down the list of possible reasons for the ventilation system not being within specifications. The decision point for moving forward can be summed up best as "is there an obvious explanation for the system degradation?" If the answer is "Yes," then either Civil Engineering or Facilities Maintenance should be contacted to correct the situation. If there is no obvious explanation, it is recommended to begin troubleshooting the ductwork by collecting measurements to narrow down the possible locations for the cause of the degradation (Ref 8).

12.2. Baseline Deviation Method. This method is described in detail in the ACGIH operations and maintenance manual, and to begin the process it requires the user to collect static pressure measurements for all sampling points in the system. Using a spreadsheet, create a table for each sample point along with the measured static pressure and baseline static pressure. Next, calculate the percentage difference from the baseline value using Equation 12 and insert the results into Table 5 below. The criterion for how to rate the "Within limits?" column is based on the ± 20% variability for static pressure baseline values listed in section 11.1. If the percentage of the baseline calculation result is ± 20%, then input "Yes" into the appropriate column. If the percentage of the baseline result is above 20%, then list as "High," and if less than 20% then list as "Low" (Ref 8).

$$\text{Percentage of Baseline}=\left[\frac{(\text{Measured SP-Baseline SP})}{\text{Baseline SP}}\right]\times 100\% \qquad (12)$$

Table 5. Baseline Deviation Method Spreadsheet

Sample Location	Measured Static Pressure	Baseline Static Pressure	Percentage of the Baseline	Within Limits? Yes/High/Low
1	-2.5	-1.36	+84	High
2	-3.68	-3.76	-2.1	Yes
3	-5.69	-7.35	-23	Low

12.2.1. Interpretation of the Baseline Deviation Method. If the result in the spreadsheet is "High," there is too much airflow in this hood or section of the ventilation system. Having too much airflow in one section of a ventilation system (assuming no losses in the system) means there is at least one hood or section with too low airflow, which would result in a "Low" rating. If the entire system is "Low," then there is likely an issue with the fan or with the air-cleaning device. In general, static pressure measurements "should be collected downstream (toward the fan) until the blockage is found (between the most proximal static pressure showing an increase in static pressure and the point previous)." "An increase in SP (higher suction) may indicate that a blockage exists somewhere upstream of that point toward the hood. Measurements should be collected upstream until the blockage is found (between the most proximal branch showing a decrease in SP and the point previous)." A final note: "if a very small measured SP is found it may indicate a complete blockage in the line between the hood and the fan" (Capt Horenziak, *AFIT Engineering Controls Guide: Industrial Ventilation*, Dec 2009; contact AFIT/ENV for a copy of this document).

12.3. Additional troubleshooting helpful hints are listed below verbatim from the OSHA *Technical Manual, Appendix III:3-4. Troubleshooting an Exhaust System* (Ref 10):

If the air flow is low in hoods, check:

- Fan rotation (reversed polarity will cause fan to run backwards; a backward-running centrifugal fan delivers only 30-50% of rated flow);
- Fan RPM;
- Slipping belt;
- Clogged or corroded fan wheel and casing;
- Clogged ductwork (high hood static pressure and low air flow may indicate restricted ducts; open clean-out doors and inspect inside ducts);
- Closed dampers in ductwork;
- Clogged collector or air cleaning devices;
- Weather cap too close to discharge stack (a 3/4 duct- diameter gap should exist between cap and stack; weather caps are not recommended);
- Poorly designed ductwork (short radius elbows); (branch entries enter main duct at sharp angles); (ductwork diameter too small for the air-flow needed; and
- Lack of make-up air (high negative pressures affect propeller fan system output; lack of supplied make-up air causes high airflow velocities at doors and windows).

If the air flow is satisfactory in a hood but contaminant control is poor, check:

- Crossdrafts (from process air movements); (worker-cooling fans and air-supply systems); (open doors and windows);
- Capture velocity (work operation too far from hood opening);
- Hood enclosure: (door, baffles, or sides may be open or removed); and
- Hood type: (canopy hoods are inappropriate for toxic materials).

13.0 Manometers, Magnehelic Gauges, and Visual-Only Indicators. Manometers are devices used to measure static pressure in a duct. They are frequently seen in laboratory hoods or installed in a duct in other ventilation areas. The advantage of using manometers is that they are relatively cheap and accurate and provide maintenance personnel a measurement result that can be used when verifying ventilation system functionality. It is highly encouraged to purchase manometers for applications where continuous static pressure measurements would benefit the worker. The manometer can even be purchased with a multi-colored lens to show the worker the acceptable range of static pressure measurements in a duct. If the worker inspects the manometer and finds the system is out of the acceptable range, he or she could be instructed to call Civil Engineering to fix the problem and BE to determine how the variance affects the health of the worker once the baseline is established (*AFIT Engineering Controls Guide: Industrial Ventilation*; see citation on p. 16).

13.1. Magnehelic gauges are pressure differential sensors frequently used in ventilation operations. They can be used to monitor static pressure (both positive and negative) and air velocity. Frequently, these gauges are used in paint booths to monitor the pressure drop across multi-stage filters. Multi-stage filter systems are used to remove hazardous air pollutants from the air inside a paint booth prior to being discharged through the exhaust stack. Monitoring the pressure across the filter is a method to determine when to replace the filter. There comes a point when the filter being used is no longer efficient in removing particulates. As the filter collects media, the number of pores for particles to flow through diminishes, and assuming a constant volumetric flow rate through the filter, the pressure measured by the gauge will increase. Monitoring of the magnehelic gauges will allow the shop supervisor to know when the filters are no longer operating in the efficient range and should prompt this individual to change the filter when necessary (*AFIT Engineering Controls Guide: Industrial Ventilation*; see citation on p. 16).

13.2. Visual-only indicators are used to illustrate to the worker the pressure relationship of the room without having to use a smoke tube or a flutter-strip during a workshift. This type of pressure measuring device would be very useful in a medical setting where room pressure relationships vary depending on the use of the room. One of the most common of these devices is a ball-in-tube design. This device consists of a red or green ball that is inserted in a tube, which is installed in the wall of a room, and requires a minimum pressure differential of 0.001 inches of water column to operate properly (Ref 11).

14.0 When to Assign a Risk Assessment Code to a Ventilation System. When a ventilation system fails its periodic surveillance, is out of service, or requires repair, several steps need to be taken to try to get the system back in compliance. Normally, failures in periodic surveillance can be fixed quickly by maintenance personnel (replacing filters or adjusting the system) to bring the system back in compliance.

14.1. The situation becomes more complicated when the system cannot be fixed in a timely manner. By definition, the ventilation system is used to control an occupational health hazard or the shop should not be on the ventilation surveillance schedule. Use AFI 91-202, *The US Air Force Mishap Prevention Program*, attachment 7, Risk Assessment Codes, for estimating the probability and severity of the exposure to the workers given the ventilation system is not working properly (Ref 12). Additionally, record the deficiency in DOEHRS, which will calculate a risk assessment code. If this situation exists, it is critical to communicate the issue to your leadership as well as to the shop's leadership to try to develop a resolution. Additionally, it is recommended as a best practice to keep the major command BEE updated on the status of the situation.

15.0 Annual Program Review/Inspection. An annual program inspection should be conducted as part of the annual OEH Program Management Review to ensure that all requirements were met during the previous year. Additionally, it is also advised that a program review be conducted prior to changing ventilation program managers. It should be thorough enough to ensure that the new program manager is starting with a program that is in compliance.

15.1. For the annual review, it is recommended that the ventilation program manager gather all the data necessary to present a program review to the flight commanders each calendar year. The review should include all applicable regulatory requirements and utilize the current Health Services Inspection and Environmental, Safety and Occupational Health Compliance Assessment and Management Program checklist to determine compliance with regulatory issues. Additionally, the inspection report should address the questions listed in section 15.2.

15.2. Annual Review Questions**.**

- Were all of the required periodic ventilation surveys completed for the year?
- Were any systems added to or removed from the ventilation program during the year?
- Were there maintenance issues with any of the ventilation systems during the previous year? If so, was the ventilation system restored to an acceptable level?
- Is the ventilation monitoring equipment still in good working order or should new equipment be purchased to replace damaged/aging equipment?
- Was specific training conducted during the year with respect to proper collection of ventilation data?
- Is there any air sampling that needs to be accomplished to verify a need for ventilation use as a control?
- Provide a summary of the completeness for data entry into DOEHRS.
- Provide a summary of any significant regulatory changes in the past year that have affected this program.

16.0 Corrosion Control Ventilation Design Criteria Requirements. Typical processes for a corrosion control shop include abrasive blast booths and cabinets, combustible and flammable materials storage, and a variety of paint booths. The following design standards were obtained from the ACGIH ventilation design manual 27th edition and are specific to the operations conducted in a typical corrosion control facility (Ref 9).

16.1. Abrasive Blasting Booths (Figure VS-80-01). The ventilation requirements for abrasive blasting booths can be found in the design version of the ACGIH ventilation manual, 27th edition. For abrasive blasting rooms, use Figure VS-80-01 to determine the required volumetric flow rate per area of floor space for downdraft booths [Q = 60-100 flow rate at actual condition divided by feet squared (acfm/ft^2)] and volumetric flow rate per area of the wall for crossdraft booths (Q = 100 acfm/ft^2). The minimum duct velocity for the branch leading to the dust collector is 3500 feet per minute (fpm) for both crossdraft and downdraft abrasive blasting booths (Ref 9).

16.2. Abrasive Blasting Cabinet (Figure VS-80-02). The ventilation requirements for an abrasive blasting cabinet can be found in the design version of the ACGIH ventilation manual, 27th edition. For abrasive blasting cabinets, use Figure VS-80-02 to determine the ventilation requirements. The measurements of importance are: achieve 20 air changes per minute and have a minimum duct velocity for the branch leading to the dust collector of 4000 fpm (Ref 9).

16.3. Paint Mixture Storage Room (Figure VS-75-30). The ventilation requirements for a paint mixture storage room can be found in the design version of the ACGIH ventilation manual, 27th edition. Figure VS-75-30 recommends a range of 10-12 air changes per hour (ac/hr) with the room under a slightly negative pressure. The minimum duct velocity is 2000 fpm (Ref 9).

16.4. Paint Booths (Figures VS-75-01, VS-75-02, VS-75-04 and VS-75-05). The ventilation requirements for paint booths can be found in the design version of the ACGIH ventilation manual, 27th edition. There are several types of paint booths listed in the design manual including Large Paint Booth (Figure VS-75-01), Small Paint Booth (Figure VS-75-02), Large Drive-Through Spray Paint Booth (Figure VS-75-04), and Paint Booth Vehicle Spray (Figure VS-75-05) (Ref 9).

16.4.1. Large Paint Booth (Figure VS-75-01). For an air spray, large walk-in paint booth, the volumetric flow rate is determined by Q = 100 acfm/ft^2 multiplied by the measured area of the filters with a minimum duct velocity of 2000 fpm. If the worker is using an electrostatic or high volume low pressure (HVLP) spray gun, then the volumetric flow rate is reduced to 60 acfm/ft^2 (Ref 9).

16.4.2. Small Paint Booth (Figure VS-75-02). For an air spray design, the volumetric flow rate is Q = 200 acfm/ft^2 for a filter face area of up to 4 ft^2. When the filter face area is greater than 4 ft^2, the volumetric flow rate is determined using Q = 150 acfm/ft^2. As in the case with large paint booths, if the worker is using an airless spray gun, then the volumetric flow rate is determined by Q = 125 acfm/ft^2 for a filter face area of up to 4 ft^2; when the filter face area is greater than 4 ft^2, the volumetric flow rate is determined using Q = 100 acfm/ft^2 (Ref 9).

16.4.3. Large Drive-Through Spray Paint Booth (Figure VS-75-04). For an air spray design, the volumetric flow rate is determined by Q = 100 acfm/ft^2 multiplied by the measured area of the filters with a minimum duct velocity of 2000 fpm. If the worker is using an electrostatic or HVLP spray gun, then the volumetric flow rate is reduced to 60 acfm/ft^2 (Ref 9).

16.4.4. Paint Booth Vehicle Spray (Figure VS-75-05). For an air spray design, the volumetric flow rate is Q = 100 acfm/ft^2 for a filter face area of up to 150 ft^2. When the filter face area is greater than 150 ft^2, the volumetric flow rate is determined using Q = 50 acfm/ft^2. If the worker is using an electrostatic or HVLP spray gun, then the volumetric flow rate is determined by Q = 60 acfm/ft^2 (Ref 9).

17.0 Medical Facility Requirement Standards. For medical facilities, the design version of the ACGIH ventilation manual only contains design criteria for mortuary tables. From this manual, the criterion for mortuary tables is located in Figure VS-99-07 and requires a total volumetric flow rate of 725 acfm with slot and duct velocity at 2000 fpm (Ref 9).

17.1. Disease Isolation and Protective Isolation Rooms. Disease isolation rooms are used in medical facilities for patients suffering from an infectious disease such as tuberculosis, etc. The disease isolation room is designed with engineering controls to prevent the spread of disease by maintaining a negatively pressurized relationship to the outside of the room. The United Facilities Criteria (UFC) 4-510-01, *Design: Medical Military Facilities*, and Centers for Disease Control and Prevention (CDC) *Guidelines for Environmental Infection Control in Health-Care Facilities* recommend minimum total and outside air change rates of 12 air changes per hour and 2 air changes per hour, respectively, for new buildings and newly renovated HVAC systems. The total air change rate refers to "the minimum total air changes per hour required to meet ventilation requirements at design conditions. These rates are considered the minimum required for normal health and comfort consideration. Additional air may be required for temperature, dilution, and odor control, as well as air requirements for such items as hoods, glove boxes, clean-air stations, combustion equipment and dust collectors." The outside air change rate "is the minimum outside air changes per hour to meet the ventilation requirements at design conditions." For existing facilities, the recommendation is to maintain the same air change rates as a new building if physically possible and if the cost of maintaining these rates is reasonable. If it is not practicable to achieve or maintain these rates, then the minimum air changes per hour may be reduced to six total air changes per hour provided that the system is "supplemented by HEPA filtration or Ultra Violet Germicidal Irradiation systems specifically designed for tuberculosis room applications." Protective isolation rooms are designed for patients with compromised immune systems with the intent of preventing contact of the patient with an infectious disease from the general population in a hospital. The ventilation design criteria (negative pressure, minimum total and outside air changes per hour) for protective isolation rooms are the same as the disease isolation room design criteria (Ref 13).

17.2. For all other areas within the medical facility, it is recommended to use the following references: AFI 44-108, *Infection Control Program*; ANSI/ American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)/American Society for Healthcare Engineering (ASHE) STD 170, *Ventilation of Health Care Facilities*; UFC 4-510-01. For new building or renovation design criteria, review the UFC 4-510-01 document for the specifications (air changes per hour, pressure relationship) for each room in the clinic or hospital. Specifically, use the following reference (pages 281-328) for the details of 570 different types of rooms that could be in a clinic or hospital. The CDC document "*Guidelines for Environmental Infection Control in Health-Care Facilities*" should be used as a reference for existing ventilation systems along with AFI 44-108 and ANSI/ASHRAE/ASHE STD 170.

17.3. For ventilation evaluation in a clinic or hospital setting, the design criteria used to evaluate the compliance for a particular room are based upon the design standards for the year the building was completed. When new criteria or building codes are developed, the new criteria do not apply to buildings built prior to the new requirements. Only in the case where the entire ventilation system is replaced will the BE technician use the new design criteria for evaluation.

APPENDIX A

Various Dilution and Local Exhaust Ventilation Systems

The following information was obtained from a Air Force Institute for Occupational Health (AFIOH) Consultative Letter AFIOH-DO-BR-CL-2004-0010, Detachment 3, *Controls: Industrial Ventilation*, 35 AMDS/SGPB Instruction 48-1, 2005 (available at https://kx.afms.mil/kxweb/dotmil/file/web/ctb_043075.pdf to those with access) and modified to update the information as necessary. This letter can be found on the U.S. Air Force Knowledge Exchange at https://kx.afms.mil/kxweb/home.do (for those with access).

DILUTION VENTILATION SYSTEMS

Dilution ventilation provides hazard control through the supply or exhaust of air from a workspace. Typically, it is not as desirable as a local exhaust system, but in some cases, it will satisfy ventilation requirements at a much lower cost than a comparable local exhaust system. The most common areas where these systems are seen on Air Force bases include battery charging rooms, flammable/combustible materials storage areas, infection control and clean room systems, and pesticide storage areas.

Battery Charging Rooms

Ventilation of wet cell battery charging rooms is required due to the potential release of hydrogen gas. Utilizing the number of battery cells being charged and the amperage required to charge them, the theoretical hydrogen gas formation can be calculated (see Air Force Institute for Environment, Safety, and Occupational Health Risk Analysis Fact Sheet *"Industrial Ventilation"*). Using this value and the room volume, a ventilation rate in air changes per hour can be found.

The recent advent of Technical Order (T.O.) 8D2-3-1, *Operation, Service, and Repair of Nickel Cadmium Storage Batteries*, has created a requirement for ventilation in NiCad charging rooms. According to this document, charging areas will be mechanically ventilated to provide 3-4 ac/hr to ensure the removal of hydrogen gas generated. As with flammable storage areas, there is no monitoring frequency or designation of agency of responsibility. Frequency of monitoring should be determined locally.

Flammable/Combustible Materials Storage Areas

Flammable/combustible materials storage areas are regulated by 29 CFR 1910.106, *Flammable and Combustible Liquids*, and AFOSH STD 91-501, *Air Force Consolidated Occupational Safety Standard*. According to these references, areas that store Class I liquids shall be ventilated at a rate of not less than 1 $ft^3/min/ft^2$ of solid floor area. Both regulations discuss the need for a dilution system to provide a complete change of air within a flammable storage room at least six times per hour. No monitoring frequency or designation of agency of responsibility is given in either reference. Frequency of monitoring should be determined locally.

Infection Control & Clean Room Systems

Hospital and veterinary clinic infection control systems are designed to control the potential for the spread of infectious agents through the use of room dilution and removal of contaminated air. In some cases, they are also used for product protection such as in sterile supply rooms. In general, these systems have no periodic monitoring requirements, but airflow and pressure requirements, specific to each room type, can be found in AIHA, AFIOH, CDC, and ASHRAE medical guidance on the subject. Per AFI 44-108, *Infection Control Program,* semi-annual checks of the systems are essential to ensure proper flow rates and pressure relationships are maintained. Each room type has specific guidelines for room pressure and ventilation rate. It is important to note that these values do no guarantee the prevention of infection spread in a tuberculosis isolation room or the cleanliness of an operating suite; they simply are guidelines for these work areas.

Pesticide Storage Areas

Pesticide storage areas have a recommended dilution ventilation requirement of 6 ac/hr (UFC 4-218-10N, *Design: Pest Management Facilities*). The purpose of these vents is to minimize buildup of airborne pesticide dust and vapors in an enclosed area during storage. Operation of the ventilation system prior to room entry will prevent workers from potentially inhaling pesticides when first opening the storage room door. However, the vents are not needed to prevent exposures above the OEEL. Although there is no regulation driving the periodic monitoring of these rooms, annual checks are typically accomplished.

LOCAL EXHAUST VENTILATION SYSTEMS

Local exhaust systems are used in many shops to reduce exposures. While many of these systems assist with the reduction of contaminants, they all cannot be defined as control systems since they all do not reduce the level of exposure from above an OEEL or permissible exposure limit to below one. Instead, they simply assist with lowering already low exposure levels. In many cases, the determination of whether a system is defined as a control system is left to the base BE’s judgment, since shutting down a ventilation system to sample the work process poses other concerns (environmental, compliance with OSHA control guidance, etc.). Systems that qualify as local exhaust ventilation, but may or may not be control systems, include abrasive blasting booths and cabinets, biological safety cabinets, grossing tables, and laminar flow hoods, firing ranges, fuel tank purge systems, lab hoods, paint booths, pesticide mixing hoods, solvent tank systems, vehicle exhaust systems, welding and wood working/wood dust capture systems.

Abrasive Blasting Booths

Abrasive blasting is specifically regulated under 29 CFR 1910.94. Inhalation hazards associated with this task include dust generated by destruction of the blasting media and metal dust created by disintegration of the item being blasted. Typical metals found include lead, cadmium, zinc, and chromium. It is difficult to quantify all of the potential exposures associated with blasting, since every different part being blasted could have variable quantities of a wide range of metals. For these reasons, it is recommended that a booth controlling exposures to hazardous materials be monitored quarterly.

Abrasive Blasting Cabinet

These systems are commonly used in maintenance operations. Unlike the media blasting booths discussed above where the worker is physically inside the enclosure, these units are designed where the worker is outside of an enclosed system, applying the blasting media using a set of gloves built into the box. These systems have many administrative requirements outlined in 29 CFR 1910.94, *Ventilation*, which can be evaluated during routine industrial hygiene surveillance. The ventilation requirements for an abrasive blasting cabinet can either be found in the design version of the ACGIH ventilation manual, 27^{th} edition, or obtained directly from the manufacturer. If the manufacturer's recommended parameters cannot be obtained, it is recommended to follow the ACGIH recommendations found in Figure VS-80-02 on page 13-143. The ACGIH ventilation parameters are to maintain negative pressure in the cabinet with respect to the surrounding environment, achieve a minimum of 20 air changes per minute, and obtain a duct velocity for the branch leading to the dust collector of 4000 fpm (Ref 9). A base-line exposure assessment survey should be conducted for each cabinet prior to initial use to ensure the ventilation system is operating properly and to verify the seals in the cabinet are not compromised. Periodic monitoring should be determined based upon either professional judgment, or by using the flowchart in Appendix B to determine frequency of surveillance. A visual inspection of the seals and the gloves in the box is recommended during routine industrial hygiene surveillance.

Biological Safety Cabinets, Grossing Tables, & Laminar Flow Hoods

Three common hospital local exhaust systems are biological safety cabinets, grossing tables, and laminar flow hoods. Biological safety cabinets have an enclosed design that is similar to a lab hood. However, these cabinets include high efficiency particulate air (HEPA) filters that are used to control exposure to biological organisms. Due to the presence of the HEPA filters, the typical BE shop does not have the equipment or training to survey these systems, so they are usually contracted to outside agencies. Grossing tables are utilized to control preservative chemical (e.g., formaldehyde) vapor and odor during tissue dissection. They are normally surveyed according to manufacturer's procedures, and air sampling drives the need for routine surveillance. Laminar flow hoods are utilized in the pharmacy to preserve the cleanliness of drugs during dispensing, offer product protection only, and do not require periodic monitoring from BE.

Firing Ranges

Ventilation systems at firing ranges are designed to control exposures to byproducts of complete and incomplete combustion, particulate matter, and possibly metals (depending on the ammunition used). Typically, these are push-pull systems, with an air supply located behind the shooters and capture ventilation downrange. In some ways, they mimic the action of a paint booth, and they are typically surveyed in the same manner. Due to the engineering control requirements in 29 CFR 1910.1025, *Lead*, the proper function of these systems is based solely upon their ability to control exposures. Baseline surveys must be completed in conjunction with air sampling and the results utilized to establish periodic monitoring requirements. The ACGIH design manual recommends design criteria for firing ranges in Figure VS-99-04. The minimum volumetric flow rate is determined by multiplying the cross-sectional area (height and width) of the range by 50. The minimum volumetric flow rate, regardless of the size of the firing range, is 20 ac/hr (Ref 9). NIOSH recommends the velocity of the airflow at the firing line be “no more than 75 feet per minute (fpm) with a minimum acceptable flow of 50 fpm.” NIOSH also states that “if it is desired to minimize fall-out of gun emissions downrange of the firing line, downrange airflow should be maintained at a minimum of 30 fpm (0.152 m/s) and should be evenly distributed.” Lastly, NIOSH recommends the exhaust part of the ventilation system “at or behind the bullet trap” be maintained at a “minimum duct air velocity of 2500-3000 fpm” (Ref 14). From Engineering Technical Letter 11-18, *Small Arms Range Design and Construction*, May 2011 (available at https://kx.afms.mil/kxweb/dotmil/file/web/ctb_207108. pdf for those with access), a fully contained indoor range must maintain a slightly negative pressure relationship by exhausting approximately 3% to 7% more air than is supplied. Recirculation of air within the range is prohibited, and the positive exhaust must include a system for capturing and removing airborne particles. This letter recommends an air velocity at the firing line of 75 fpm with a variability of ± 15 fpm. The airflow must be evenly distributed across the firing line with a maximum variability of ± 15 fpm. A plenum is used to evenly distribute the airflow from the firing line to the bullet trap with a recommended air velocity of 400 to 600 fpm, with a maximum velocity of 2000 fpm (Engineering Technical Letter, see citation above). Additional information regarding lead-free frangible ammunition exposure at Air Force firing ranges can be found at http://www.dtic.mil/dtic/tr/fulltext/u2/a487506.pdf.

Fuel Tank Purge Systems

Purge systems are used to ventilate confined areas prior to entry. In most cases, an entry permit or technical order drives their usage. The measure of effectiveness is typically atmospheric monitoring that demonstrates the presence of adequate oxygen and the absence of harmful atmospheres. These systems can be portable or fixed, with most systems located in aircraft fuel tank maintenance facilities. Typically, a supply line is attached to one side of the tank and an exhaust line on the other side to ensure the fuel tank atmosphere is not explosive prior to personnel entrance, so it is appropriate for the BE function to monitor the supply and exhaust in conjunction with the base confined space team.

Lab Hoods

It is difficult, if not impossible, to determine if a lab hood is a control system. Lab hoods are used for a huge variety of processes, and quantifying all of the potential exposures for a given hood can be daunting. This, coupled with the fact that the hood should not be turned off during usage, normally qualifies the system as a control. Frequency of monitoring should be determined locally. (Note: Non-mandatory guidance in 29 CFR 1910.1450, Appendix A: As a rule of thumb, use a hood or other local ventilation device when working with any appreciably volatile substance with a TLV of less than 50 ppm.)

Paint Booths

A variety of paint booths can be found throughout most Air Force bases. Many of these booths are used to apply some of the most hazardous substances still found in the inventory, including chromium products and isocyanates. There are many instances where exposure monitoring of these systems has demonstrated their ability to reduce exposures from above the OEEL to below it. Each system must be examined individually using available air sampling results. The design and operating requirements for these systems are outlined in 29 CFR 1910.94, *Ventilation*, and ACGIH *Industrial Ventilation: A Manual of Recommended Practice for Design*. Additional information regarding exhaust recirculation can be found at http://www.dtic.mil/dtic/tr/fulltext/u2/a464911.pdf.

Pesticide Mixing Hoods

Most pest management facilities have a mixing hood for preparing small amounts of pesticides in 5- to 10-gallon sprayers. In some cases, these hoods can control exposures to pesticides, although adequate air sampling and a move to minimally hazardous pesticides may prove this is not the case. Flow rates are driven by requirements in UFC 4-218-10N, *Design: Pest Management Facilities*. Monitoring frequency should be based upon air sampling and pesticide usage.

Solvent Tank Systems

Solvent tanks can be found in a variety of work areas ranging from aircraft maintenance to civil engineering. The purpose of these tanks is to remove accumulated oil, grease, and grime from parts. Solvent usage in these tanks has evolved over the years from very hazardous to relatively benign. Older solvents were highly volatile and the tanks required a ventilation system mounted on the side and designed to capture rising vapors from the tank. Today's solvents are either citrus-based or paraffinic naphthas. Both of these products have low volatility and present very minimal inhalation hazards. However, in most cases, since the tanks have remained in the same locations, the ventilation systems have as well.

Vehicle Exhaust Systems

Vehicle exhaust systems are used in vehicle maintenance areas and at the Fire Department to evacuate vehicle exhaust from engines that must be run indoors. The operation of these systems is outlined in AFOSH STD 91-20, *Vehicle Maintenance Shops*. Exhaust systems can limit worker exposure to carbon monoxide, oxides of nitrogen, and sulfur dioxide. Additionally, they help to remove the carbon soot typically associated with diesel exhaust. Frequency of monitoring should be determined locally.

Welding Systems

Welding ventilation requirements are driven by 29 CFR 1910.252, *General Requirements (Welding, Cutting, and Brazing)*, and AFOSH STD 91-5, *Welding, Cutting, and Brazing*. The federal regulation requires the use of mechanical ventilation when welding is conducted in areas smaller than 10,000 ft^2 or when the room has a ceiling height less than 16 feet. Additionally, it is required if exposure levels are above the OEEL. Local exhaust ventilation is never prescribed but is offered as an option. In many cases, the ventilation systems cannot be used, since the parts being welded are too large to fit on the welding bench. In all work areas, mechanical ventilation is available, and during some times of the year, the large doors in these areas are opened to provide natural dilution ventilation as well. It is important to note that some metals used in welding have OSHA specific standards (lead, cadmium, chromium, beryllium, etc.), potentially requiring more stringent monitoring. In these cases, welding ventilation systems are routinely monitored. Note: Recent National Institute for Occupational Safety and Health

(NIOSH) research indicates neurological and neurobehavorial deficits may occur when workers are exposed to low levels of manganese in welding fumes. NIOSH is currently reviewing its recommended exposure limit for manganese as a result of these studies, so increased air monitoring for manganese should be considered. See the CDC NIOSH web page on welding (http://www.cdc.gov/niosh/topics/welding).

Wood Working/Wood Dust Capture Systems

Wood dust capture systems can be found in practically every wood shop in the Air Force. The National Fire Protection Association has placed requirements for wood dust control that are based upon the potential for an explosion hazard lower explosive limit of 40 g/m^3. However, this is not an issue with Air Force systems, since it takes a concentration roughly 40,000 times the 2012 ACGIH threshold limit value (TLV) for wood dusts other than western red cedar of 1 mg/m^3 to reach the lower explosive limit. The performance of these devices is regulated in AFOSH STD 91-10, *Civil Engineering*, which states that only machines that generate dust, vapors, or mists will be connected to an effective industrial exhaust vent system. The measure of effectiveness is simply whether the system adequately vacuums up the dust. For these reasons, most wood dust collection systems do not qualify as control systems and monitoring is unnecessary.

OTHER VENTILATION SYSTEMS

In many cases, there is confusion surrounding the designation of ventilation systems for the control of workplace hazards. When visiting work areas, HVAC systems and other engineering controls are often called ventilation. To address this, and help BE personnel understand the true nature of these systems, a summary of other systems in existence can be documented in DOEHRS, but not as a control to a hazard. However, it is generally not necessary to evaluate these systems as ventilation systems.

Anesthetic Gas Scavenging Systems

These systems are used to capture waste anesthetic gases exhausted from the patient’s mouth when an endotracheal tube does not fit well and pump it outside of the operating room. Additionally, postoperative patients in the recovery room continue to off-gas anesthetics. Depending on the anesthetic used, as well as the body mass index of the patient and time under anesthetic, levels can vary quite widely. In humans, these systems have a relatively constant exhaust flow and a recommended minimum flow rate of 45 liters per minute. The anesthetist using the calibrated flowmeter on the side of the system can verify this value. While a properly operating system limits anesthetic gas release to occupied areas, it is primarily designed and operated as a treatment delivery device, not a worker health control. For this reason, no survey of this unit is necessary. If, however, air sampling data show that concentrations of nitrous oxide are above the ACGIH TLV limits, then it is recommended to “increase air flow into the room or increase the percentage of outside air to allow for more air mixing and further dilution of the anesthetic gas.” If this does not reduce exposures, then local ventilation can be used in the form of a hood or duct to capture the anesthetic gas. Finally, if the above methods do not reduce exposures low enough, it is advised to add vents to the ceiling to direct the supply air to the room towards the floor and to place additional return vents near the floor (Ref 15).

Chlorine Gas Storage Rooms

The use and storage of chlorine gas and its ventilation requirements are regulated in AFOSH STD 91-10, *Civil Engineering*, Chapter 12. Chlorine gas is typically found on Air Force bases in water treatment areas and in pool facilities. As a minimum, each chlorinator treatment room that utilizes gaseous chlorine will be equipped with a mechanical exhaust system that is turned on prior to entering the room. Additionally, operators are warned to ensure that the fan actually turns on and that it runs for several minutes to allow any gas in the room to be evacuated. An ammonia bottle is present to verify that all of the gas has been removed.

Fans

Mobile and fixed fans are used in a variety of situations to provide comfort ventilation. In some cases, they are located in shops to aid with thermal stress and odor control. These fans normally are not used to control hazards, and therefore there is no requirement for the BE to evaluate these systems.

Irritating Odor Dilution Systems

It is common for HVAC systems and other dilution vents to be used in hangar facilities for removal of exhaust and fuel vapors typically related to aircraft run-ups outside of the hangar. BE shops may also receive requests for evaluation of HVAC systems with respect to odors being brought in from outside office areas, normally caused by vehicles or other mobile sources located near building air intakes. HVAC systems are not designed to be ventilation control systems and should not be evaluated as such.

Soldering and Bench Grinding Vacuum Systems

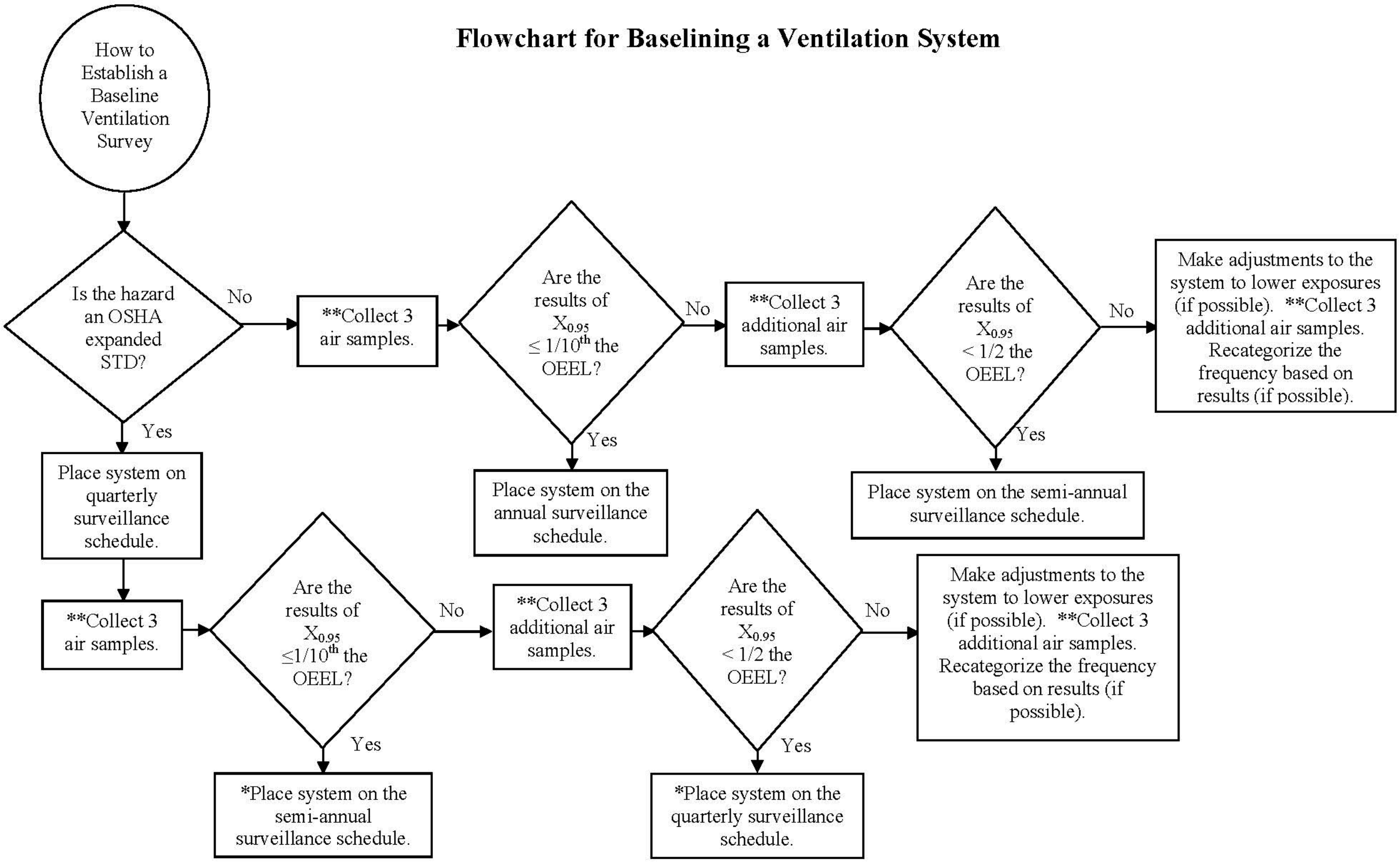
Soldering and bench grinding systems are found in many Air Force shops. Dental laboratories use these systems during denture and crown construction, communications shops use these systems during computer and telephone repair, and aircraft avionics/systems branches use them during repair of electronic equipment. In fact, these systems are simply vacuums to aid with the cleanup of waste materials. If solder constituents are not heated above their boiling points (tin – 4118 °F, lead – 3164 °F), then this operation will not pose a significant inhalation hazard to the worker as long as the soldering gun operates at approximately 700 °F, which is hot enough to melt the solder filler metals (melting points: lead – 621 °F and tin – 450 °F). Determine the frequency of surveillance locally if the above conditions do not apply.

X-Ray Processing Rooms

Many older x-ray processing facilities manually developed x-ray films using developer and fixer solutions. These solutions contained glacial acetic acid. To prevent buildup of acid vapors in the dark rooms, Kodak proposed an industry standard of 10 ac/hr in these areas. With the advent of digital processing and the phasing out of these chemicals, the need for this ventilation requirement is waning.

APPENDIX B

Flowchart for Baselining a Ventilation System



* Regardless of the results, lead will be on a quarterly surveillance schedule per OSHA.
** For sampling strategy details, see *A Strategy for Assessing and Managing Occupational Exposures, 3rd Edition.*

APPENDIX C

Cited References and Additional Ventilation Regulations and References

Cited References

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14. National Institute for Occupational Safety and Health, *NIOSH ALERT: Preventing Occupational Exposures to Lead and Noise at Indoor Firing Ranges*, Publication No. 2009-136, NIOSH, Washington, DC, April 2009, URL: http://www.cdc.gov/niosh/docs/2009-136/pdfs/2009-136.pdf. Accessed 30 Jan 2012.

15. National Institute for Occupational Safety and Health, *Controlling Exposures to Nitrous Oxide During Anesthetic Administration*, Publication No. 94-100, NIOSH, Washington, DC, 1994, URL: http://www.cdc.gov/niosh/docs/94-100/. Accessed 8 Jun 12.

Additional Ventilation Regulations and References

Below is a list of references for use in ventilation surveillance. According to the UFC hyperlink below, there are a number of agency specific documents that have been superseded by a UFC document. The most notable of these documents is the U.S. Military Handbook, which has been converted to UFC documents and, therefore, will not be referenced as such in this technical guide (http://www.wbdg.org/ccb/DOD/UFC/UFCs%20vs%20Agency-Specific%20Docs.pdf).

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- 29 CFR 1910.106, *Flammable and Combustible Liquids*, 13 September 2005
- 29 CFR 1910.107, *Spray Finishing Using Flammable and Combustible Materials*, 14 December 2007
- 29 CFR 1910.252, *General requirements (Welding, Cutting, and Brazing)*, 9 September 2009
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- 29 CFR 1910.1018, *Inorganic Arsenic*, 8 June 2011
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- UFC 4-211-01N, *Aircraft Maintenance Hangars: Type I, Type II and Type III*, 16 December 2009
- UFC 4-211-02N, *Design: Corrosion Control and Paint Hangars*, 1 April 2010
- UFC 4-229-01N, *Design: General Maintenance Facilities*, 16 January 2004
- UFC 4-510-01, *Design: Medical Military Facilities*, 4 August 2011
- UFC 4-451-10N, *Design: Hazardous Waste Storage*, 16 January 2004

LIST OF ABBREVIATIONS AND ACRONYMS

ac/hr	air changes per hour
acfm	flow rate at actual condition
ACGIH	American Conference of Governmental Industrial Hygienists
AFI	Air Force instruction
AFIOH	Air Force Institute for Occupational Health
AFOSH	Air Force Occupational Safety and Health
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
ASHE	American Society for Healthcare Engineering
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BE	bioenvironmental engineer/engineering
CDC	Centers for Disease Control and Prevention
CFETP	Career Field Education and Training Plan
CTS	Course Training Standard
df	density factor
DOEHRS	Defense Occupational Environmental and Health Readiness System
fpm	feet per minute
HEPA	high efficiency particulate air
HVAC	heating, ventilation, air conditioning
HVLP	high volume low pressure
lbm	pound mass
NIOSH	National Institute for Occupational Safety and Health
OED	Bioenvironmental Engineering Education Division
OEEL	occupational and environmental exposure limit
OSHA	Occupational Safety and Health Administration
SP	static pressure
SSP	system static pressure
STD	standard
T.O.	technical order
TLV	threshold limit value
UFC	Unified Facilities Criteria
USAFSAM	U.S. Air Force School of Aerospace Medicine
"wg	inches water gauge