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ANSI/AIHA Z9.2–2012

Fundamentals Governing the Design and Operation of

Local Exhaust Ventilation Systems

A Publication by
American Industrial Hygiene Association®

BY THE ANSI/AIHA Z9.2 SUBCOMMITTEE

ANSI

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Protecting Worker Health

ANSI/AIHA® Z9.2–2012

American National Standard — FundamentalsG overning the Design and Operation of Local Exhaust Ventilation Systems

Secretariat

American Industrial Hygiene Association

Approved: March 6, 2012

American National Standards Institute, Inc.

American National Standard

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Contents

Note: Standard Paragraphs denoted with a "See Appendix" indicate that there is an entry in the Appendix for that Paragraph which provides additional explanatory information on the Paragraph topic.

Foreword

This standard describes fundamental good practices related to the commissioning, design, selection, installation, operation, maintenance, and testing of local exhaust ventilation (LEV) systems used for the control of employee exposure to airborne contaminants. It is intended for use by LEV system owners, employers, industrial hygienists, facility engineers, maintenance personnel, testing and balancing personnel, ventilation system designers, and others with responsibility for LEV systems. It is compatible with the ACGIH® *Industrial Ventilation Manual* and other recognized standards of good practice.

A document describing fundamentals of exhaust system design was originally published in 1936. This was formalized by the Z9 Committee under the direction of Knowlton Caplan, and published in 1960, with updates in 1971 and 1979. The 2001 edition, under the direction of Jeff Burton, constituted a major revision of that earlier document and was a more performance based document with a systems orientation that appealed to a wider audience. Much of the previously included technical design detail had been left to other, more thorough and comprehensive sources. This 2012 version is an additional update of the 2006 updated version.

How to Read this Standard

The standard is presented in two column format. The left column presents the requirements of the standard; the right column provides clarification and explanation of the requirements plus “how to comply” information. Appendix A provides supplementary information by Standard section number. The designation, “(See Appendix)”, at the end of a section designates an Appendix entry for that section and paragraph.

Requirements should be considered minimum criteria and can be adapted to the needs of the User establishment. Demonstrably equal or better approaches are acceptable. When deviating from the Standard, documentation should be provided. The Standard is auditable by those trained in local exhaust ventilation. An Audit Form is provided in Appendix B.

Suggestions for improvement of this standard are welcome. The Committee will carefully consider all comments and suggestions. Comments should be sent to Attn: Scientific and Technical Initiatives, AIHA®, 3141 Fairview Park Drive, Suite 777, Falls Church, VA 22042.

This standard was processed and approved for submittal to ANSI by the Z9 Accredited Standards Committee on Health and Safety Standards for Ventilation Systems. Committee approval of the Standard does not necessarily imply that all committee members voted for its approval. At the time it approved this Standard the Z9 Committee had the following members:

Thomas C. Smith, Chair
Theodore J. Knutson, PE, Vice Chair
David Hicks, Secretariat Representative

Organization Represented	***Name of Representative***
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L.J. DiBeradinis
G. Hrbek, as a Technical Resource

American National Standard — Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems

Requirements of the Standard

1. Scope

1.1 This Standard establishes minimum requirements for the commissioning, design, specification, construction, and installation of fixed industrial local exhaust ventilation (LEV) systems used for the reduction and prevention of employee exposure to harmful airborne substances in the industrial environment.

1.2 The Standard also establishes fundamental requirements for the management, operation, maintenance, and testing of LEV systems to assure satisfactory performance over the life of the system.

1.3 The Standard also describes basic requirements for replacing air exhausted from the space.

1.4 The Standard does not cover:

- ventilation for comfort,
- air moving systems which are part of an industrial process,
- paint booths not used primarily for employee protection, or
- energy conservation

except when they also impact or apply to airborne contaminant control for employee protection.

1.5 Where Standard provisions are in conflict, the more stringent shall apply.

Clarification and Explanation of the Requirements

1. Scope

1.1 Local exhaust ventilation is an important engineering control technique for maintaining acceptable air quality in the industrial work environment. Its major approaches are the capture, control, or containment of airborne contaminants at or as close as possible to the point of contaminant generation. LEV is often used with other control methods, e.g., isolation, dilution ventilation, or personal protective equipment. Properly designed, installed and operated, LEV systems can provide excellent control of airborne contaminants.

1.3 Replacement air systems that are improperly designed, installed or operated can impair otherwise acceptable LEV systems.

1.4 No ventilation standard can provide complete and comprehensive coverage of every application and technical problem encountered when applying LEV systems to the wide range of processes and equipment found in industry. The User should refer to appropriate technical references and publications for further guidance on uses and applications of local exhaust in specific applications. (See Appendix)

1.5 Because some sections are written to stand alone, they may duplicate requirements of other sections. Efforts to avoid conflicts within the Standard have been taken but every consensus and committee-generated standard has the possibility of conflicts.

2. Referenced Standards and Publications

The following codes, regulations, standards, and guidelines contain provisions that, through reference in this standard, constitute provisions of the Standard. Where published requirements are in conflict, the more stringent shall apply. Information on how to obtain the following documents is available in Appendix A. Check Appendix A for the corresponding number in parenthesis.

2.1 American National Standards.

ANSI/AIHA® Z9.1 thru ANSI/AIHA Z9.11 Standards on industrial ventilation, as follows:(1)

ANSI/AIHA® Z9.1 *Open-Surfaced Tanks Ventilation and Operation*;

ANSI/AIHA® Z9.3 *Spray Finishing Operations–Safety Code for Design, Construction, and Ventilation*;

ANSI/AIHA® Z9.4 *Abrasive Blasting Operations–Ventilation and Safe Practices for Fixed Location Enclosures*;

ANSI/AIHA® Z9.5 *Laboratory Ventilation*;

ANSI/AIHA® Z9.6 *Exhaust Systems for Grinding, Buffing and Polishing*;

ANSI/AIHA® Z9.7 *Recirculation of Air from Industrial Process Exhaust Systems*;

ANSI/AIHA® Z9.10 *Fundamentals Governing the Design and Operation of Dilution Ventilation Systems in Industrial Occupancies*; and

ANSI/AIHA® Z9.11 *Laboratory Decommissioning*;

ANSI/ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*;

ANSI/ASHRAE 55, *Thermal Environmental Conditions for Human Occupancy*;

ANSI/ASHRAE 52.1, *Gravimetric and Dust-Spot Procedures for testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter;* 52.2, *Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size*

ANSI/ASHRAE 110, *Method of Testing Performance of Laboratory Fume Hoods.*(2)

ANSI F3.1, *Welding Fume Control with Mechanical Ventilation*.

2. Referenced Standards and Publications

The items listed in Sections 2.1 to 2.3 are not all-inclusive but are considered current and recognized standards of good practice. All regulations, standards. and guidelines are subject to revision. Users of the Standard are encouraged to consult the most recent versions or editions of the regulations, standards and guidelines to determine continued applicability.

- Citations are listed in alphabetical order.
- Standards and dates may change over time. Refer to latest versions of standards to determine current applicability.
- Numbers in parenthesis refer to addresses provided in Appendix A.
- Additional technical resources are provided in Appendix A. These explain and demonstrate the application of the standards of good practice found in the citations of Section 2.

2.3 NFPA Standards.

NFPA 91, *Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids*; NFPA 45, *Fire Protection for Laboratories Using Chemicals*; NFPA 33, Standard for Spray Operation Using Flammable or Combustible Materials[3]

2.3 Occupational Safety and Health Administration Standards.

Code of Federal Regulations, Title 29, Part 1910, Section 94, Ventilation.[4]

Code of Federal Regulations, Title 29, Part 1910, Subpart Z, Toxic and Hazardous Substances.[4]

Federal standard 29 CFR 1910.94 lists four standards adopted from earlier versions of ANSI Z9 standards on ventilation of open surface tanks, spray finishing operations, abrasive blasting, and grinding, buffing, and polishing. (Use latest versions and watch for changes.)

Code of Federal Regulations, Title 29, Part 1910, Section 1450, Occupational Exposures to Hazardous Chemicals in Laboratories, May 1, 1990.[4]

2.4 Other Recognized Standards and Guidelines of Good Practice

Air Force Manual 48-155; Oct 2008 – *Occupational Health and Safety Controls*.[5]

AFOSH Standard 161-2. Please see the Appendix for more information on latest Air Force standards and guidelines.

ASHRAE Handbook *Fundamentals*. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.[2]

ASHRAE Handbook *HVAC Applications*. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.[2]

ASHRAE Guideline 1. *The HVAC Commissioning Process*; Guideline 4, *Preparation of O&M Documentation for Building Systems*.[2]

Heating and Cooling for Man in Industry, American Industrial Hygiene Association.[1]

Industrial Ventilation: A Manual of Recommended Practice for Design and *Industrial Ventilation: A Manual of Recommended Practice for Operation and Maintenance* (two volumes), Latest Editions. Cincinnati, OH: Committee on Industrial Ventilation of the American Conference of Governmental Industrial Hygienists.[(6)]

SMACNA publications: Accepted Industry Practice for Industrial Duct Construction; Rectangular Industrial Duct Construction Standards; Round Industrial Duct Construction Standards; Guide for Steel Stack Construction; Testing, Adjusting, and Balancing HVAC Systems.[(7)]

Although not intended for LEV systems, ASHRAE Guideline 1 provides a model of how commissioning can be performed.

The 28th Edition of the ACGIH® *Industrial Ventilation Manual* is due to be issued in early 2014.

3. Definitions

The following definitions explain terms used in this Standard.

3.1 Air Cleaning Equipment. A device or combination of devices for separating contaminants from the air handled by an LEV system.

3.2 Aspect Ratio. In rectangular exhaust openings, usually the ratio of the width to length of the hood opening, e.g., in slot or face openings; in ductwork, the ratio of the height to width of the duct cross-sectional dimensions.

3.3 Balanced. In LEV, a balanced system is one in which the desired air flowrate is achieved simultaneously in all branches of the system. Balance is usually achieved through good design, proper fitting and duct selection, and, when necessary, by the use of balancing dampers.

3.4 Baffle, also Flange. Partial enclosures in and around emission sources that improve or enhance airflow patterns at the emission source and at the hood. Baffles and flanges can minimize cross drafts, increase hood efficiencies, reduce airflow requirements, increase control or hood face velocities, reduce costs, and improve hood containment performance.

3.5 Branch. A duct connecting an exhaust hood to a main or submain.

3.6 Coefficient of Entry. A unitless factor, designated in the literature as Ce, which relates static pressure loss at a hood to velocity pressure in the duct serving the hood. The Coefficient of Entry is usually calculated as (VPave/SPloss)0.5. Used in design; Coefficients of Entry are published in the LEV literature for many hoods; see also, Loss Factor.

3.7 Commissioning, Commissioning Plan. A process or plan in which a local exhaust ventilation systems performance is identified, verified, and documented before, during, and after design, construction, or remodeling to assure proper operation and compliance with codes, standards, and User intentions. Commissioning ends when tests and demonstrations have verified that the system operates as intended. A Commissioning Agent is often used to administer the commissioning process, tailored to the needs of the system.

3.8 Contaminant. Also, Air Contaminant, Stressor. A substance (smoke, dust, fume, mist, vapor or gas) whose presence in air is harmful, hazardous, or a nuisance to humans.

3.9 Control Velocity. Also, Capture Velocity. The velocity of air at a point in space sufficient to draw contaminants and contaminated air into an exhaust hood.

3.10 Design. The process that includes characterizing the interactions between emissions, workers, and the air; determining appropriate air flowrates, static pressures, and other operational parameters; specifying equipment and system components.

3.11 Designer. Persons charged with designing an LEV system; may include mechanical engineers, industrial hygienists, and others with design education and experience. See 3.10 for a definition of design.

3.12 Document; to Document; Documentation. The formal process of planning and recording of the rationale for decisions made by the User, the designer, or others. Also, the written procedures developed for operating, testing, and maintaining an LEV system.

3.13 Ductwork. Elongated rigid or flexible enclosures used to convey air and entrained contaminants from one location to another.

3.14 Entry. The point at which a segment of ductwork (i.e., branch or submain) enters another segment of ductwork (i.e., submain or main); entry from a hood to a duct; and entry from a plenum to a duct.

3.15 Exhaust Hood. A shaped opening designed to capture or control chemical emissions and other air contaminants. An exhaust hood typically encloses, captures, receives, and/or removes emissions or contaminated air from process equipment enclosures, or directly from an emission source. The major exhaust hood types include the "enclosing hood," the "capture hood," and the "receiving hood." The "enclosing hood" essentially surrounds the emission source; the "capture hood" is external to the emission source and relies on "capturing" the emission by removing the air into which the chemical contaminant is emitted; the "receiving hood" is a passive hood that relies on the emission and contaminated air moving into the hood by natural means. e.g., by gravity or momentum. The basic term "Exhaust Hood" also applies to exhaust ventilated enclosures, exhaust ventilated tools, and exhaust apparatus or devices attached or integral with the process equipment when it is used, in part, for employee exposure protection. The exhaust hood normally encloses as much as possible the locations where the contaminant is released or creates air flow through the zone or zones of contaminant release of such magnitude and direction as to capture and carry the contaminated air into the exhaust system. Exhaust hoods and exhausted enclosures may also serve to keep materials within the process by preventing their dispersion.

3.16 Exhaust Rate. Also, Exhaust Volume Flowrate, Air Flowrate. Air volume flowrate through an exhaust hood.

3.17 Exhaust System, LEV System. A mechanical system for removing contaminated air from a space, comprised of one or more of the following elements: exhaust hood, ductwork, air cleaning equipment, exhauster or fan, and stack. An exhaust system operates as a functional entity and the performance of all parts is affected by the design and performance of all other parts.

3.18 Face Velocity. Average velocity of the air in the plane of a hood opening with a directional vector perpendicular to that plane.

3.19 Fan. Also, Exhauster, Ejector. Mechanical device used to provide pressure and move air through an LEV system.

3.20 Flowrate. See Exhaust rate.

3.21 Hood. See Exhaust Hood.

3.22 IH, Industrial Hygiene, Industrial Hygienist, Certified Industrial Hygienist (CIH). The profession and the professional devoted to the anticipation, recognition, evaluation and control of employee exposures to airborne contaminants. A CIH is an IH certified by the American Board of Industrial Hygiene.

3.23 IDLH. Immediately Dangerous to Life or Health, as defined by appropriate authorities.

3.24 LEV. Local Exhaust Ventilation; see Exhaust System.

3.25 Loss Factor. A unitless factor (designated variously in the literature as F, K, or k) that relates static pressure loss to velocity pressure in system fittings and equipment. The loss factor at standard conditions is usually calculated as SPloss/VPave. Necessary for design, many loss factors are published in the LEV literature.

3.26 Main. A duct or pipe connecting two or more branches or submains to the fan, exhauster or air cleaning equipment.

3.27 Makeup Air. Also, Replacement Air or Supply Air. Outside or acceptably clean air supplied to replace air that is exhausted through an LEV system. Makeup air commonly refers to building ventilation while replacement air refers to air replaced as part of the industrial process, but overlap occurs in usage. It may or may not include air provided for comfort.

3.28 Occupational Exposure Limit (OEL). A concentration of contaminant in air not to be exceeded in the breathing zone of employees. Published OELs include: Permissible Exposure Limit (PELs; established by OSHA) Workplace Environmental Exposure Levels (WEELs®, sponsored by AIHA®), Recommended Exposure Limits (RELs, sponsored by NIOSH), and Threshold Limit Value (TLVs®; sponsored by ACGIH®). In some cases the User may develop in-house OELs (i.e., when published OELs are not available).

3.29 OH&S Professional. Someone who by training, experience and/or appropriate certification is qualified to work in the field of occupational health and safety.

3.30 Periodic. 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.

3.31 Recirculated Air. Air that meets the requirements of ANSI/AIHA® Z9.7, latest version.

3.32 Replacement Air. See Makeup Air.

3.33 Slot Velocity. The average velocity of the air in the plane of the slot with a directional vector perpendicular to that plane.

3.34 SOP, System Operating Point. A combination of the desired or actual air flow and static or total pressure in an LEV system; usually used in fan selection. Also, the point where the system curve and the fan curve intersect on a graph of pressure vs. flow.

3.35 Standard Conditions, Standard Dry Air. Air at 70°F (20°C) and 29.92 inches Hg (101,325 Pa; 14.696 psia) absolute pressure, with little or no moisture content, weighing 0.075 lbs/cu foot (1.2 kg/cu meter).

3.36 Standard, the Standard. Refers to this American National Standard: ANSI/AIHA® Z9.2–2012.

3.37 System Effect Loss. A loss of fan performance (both pressure and volume flowrate) created when inlet and outlet conditions at the fan are not ideal, e.g., an elbow is mounted directly on the inlet to the fan.

3.38 Transport Velocity. The air velocity in ductwork required to prevent dry air contaminants from settling out in the ductwork; also, Scouring Velocity.

3.39 User. In this Standard, User refers to the person assuming immediate and ultimate responsibility for the design, operation and/or maintenance of an LEV system or a component of the system; could include the employer, owner, foreman, architect, engineer, and/or other responsible persons.

4. General Requirements

4.1 Persons designing, operating, maintaining, or testing an LEV system shall be qualified by training or experience to perform the job.

4.2 Design and operation of LEV systems shall be based on the following minimum baseline data:

- Emission source behavior and characteristics
- Air behavior in the space
- Worker interaction with emission sources

4. General Requirements

4.1 Designers, for example, should be trained in the basics of fluid mechanics, local exhaust ventilation, and industrial duct system design; operators of the equipment should be trained in system function and how to determine proper performance; testing personnel should be trained in testing and balancing procedures; maintenance personnel should be trained in safe maintenance functions. (See Appendix)

4.2 The information items listed below should be developed by the User. Some items often cannot be answered with much accuracy, but there should be an estimation for each. (See Appendix)

Emission source behavior:

- Location of emission sources, or potential emission sources
- Determination of emission sources that contribute to exposure
- The (potential) contribution of each source to exposure
- Characterization of each contributor, e.g., chemical composition, temperature, rate of emission, direction of emission, initial emission velocity, continuous or intermittent, time intervals of emission, MSDS (Material Data Safety Sheet), TLV, IDLH, LEL, LFL (lower flammability limit), and so forth.

Air behavior:

- Air movement in the space (e.g., direction, velocity)
- Characterization of the air (e.g., air temperature, mixing potential, supply and return flow conditions, air changes per hour, effects of wind speed and direction, effects of weather and season).

Worker behavior and interaction:

- Worker behavior and interaction with emission sources and contaminated air.
- Characterization of employee involvement (e.g., worker placement, work practices, worker education and training, cooperation).

4.3 LEV system design and specifications shall be reviewed by those knowledgeable in LEV applications before construction or installation begins.

4.3 This provision will help to assure successful and reliable service. Each professional discipline should review for its own purposes: Industrial hygienists may review to assure that adequate emission control will be achieved; seismic engineers, earthquake protection; fire experts, explosion and smoke controls; safety engineers, safe operating conditions; and so forth.

The review should include such matters as: hood placement and enclosure, compatibility with work practices, air volume flowrates, static pressures throughout the system, transport velocities, fan pressures, stack height and locations, fire protection, potential for explosions in ductwork and air cleaners, ease of maintenance, air emissions, etc.

4.4 LEV system designs and specifications shall conform to provisions of this Standard, or to other published standards of good practice if demonstrably equal to or more stringent than this Standard.

4.4 Sources of standards of good practice are summarized in Section 2 of Appendix A. See also Section 12 on Commissioning.

4.5 The LEV system shall be designed, installed, and accepted in accordance with a Commissioning Plan approved by the User.

4.5 See Section 12 for details on commissioning.

4.6 Exhaust volume flowrates and equipment sizes shall be selected to dilute air contaminants to an acceptable concentration in the LEV system.

4.6 The designer, working with the User, should determine proposed LEV system usage and, using appropriate dilution/concentration prediction equations, determine likely airborne contaminant concentrations in the LEV system during various operations. Limits should be established and documented where appropriate. For example: "dilution to below one-half of the IDLH in the ductwork," or "to below 25% of the LFL during normal operation or worst credible accident," etc. Such limits should be chosen by the User at the exhaust stack, in consultation with a qualified industrial hygienist or other OH&S (Occupational Health and Safety) professional.

4.7 Static pressure losses throughout the LEV system shall be estimated before fans are chosen and before construction or installation begins.

4.7 Flow rates, power consumption, filter efficiencies, costs and system performance are related to static pressure. No system can be properly designed or operated without first estimating (calculating or determining) static pressure demands throughout the system.

4.8 The LEV system shall be constructed throughout with structurally appropriate and chemically compatible materials.

4.8 This may include, for example, fire-rated fiberglass for acidic air streams and galvanized steel for solvent vapor air streams with sufficient thickness for the intended life of the system. LEV systems should be constructed such that at maximum concentrations, chemicals carried in the air stream are also compatible with each other and hood, duct and fan materials. See also Sections 7 and 8.

4.9 LEV systems shall be provided with performance monitoring capabilities.

4.9 Performance monitoring systems or equipment selected by the User could include analog or digital flow monitors, smoke detectors, gas detectors, or other equipment or procedures, depending on need and feasibility. LEV systems are often provided with static pressure taps located in the duct serving the hood (before any dampers and close to the hood) because the air flowrate at the hood is often the most cost-effective performance measure of an LEV system and the hood static pressure can be related mathematically to the air flowrate at the hood. See References for more information.

4.10 LEV systems shall be provided with equipment redundancy as appropriate to assure continuous protection of employees.

4.11 The LEV system shall be kept clean and free of fire, smoke, and explosion-producing materials, and maintained in good working order throughout its working lifetime.

4.12 LEV equipment suppliers shall not claim compliance with this Standard.

4.13 Users of this standard shall not claim compliance with this Standard unless every applicable element is complied with.

4.10 Redundancy is necessary when LEV equipment failure could result in substantial hazards to employees, e.g., overexposure to airborne contaminants. Redundancy could include such backup devices as auxiliary fans, emergency and standby power supplies, multiple sampling taps, and so forth, depending on need.
The designer should work with the User to determine appropriate redundancy and testing protocols for such redundant systems. See Sections 7.4 and 14 for related information.

4.11 This requirement does not prohibit the use of fire, smoke, or explosion-producing chemicals in an LEV hood when required for the process being safely conducted in the hood.

The commissioning process and periodic inspections can help assure the LEV system is maintained free of such materials. See Section 14.7.

Many fire safety guidance groups, e.g., the US Chemical Safety Board, recommend that LEV system Users evaluate potential incompatibilities if and when dusts, fume or vapors are intermixed in the LEV system to ensure that such mixtures do not result in fire or explosion hazards or destructive corrosion. Consult with such standards as ASTM 2012-00 (2003-08-IR1-R6) and others provided in Standard Section 2.

4.12 Claims of compliance with the standard—for a manufactured hood, for example—may be misleading because improper installation or operation could invalidate compliance and create a false sense of security.

5. Plant Layout and Construction

5.1 LEV design shall consider plant layout and construction. At a minimum, design shall consider items listed in Sections 5.1.1 to 5.1.5.

5.1.1 Location of Processes.

5.1.2 Location of Equipment.

5.1.3 Placement of exhaust and makeup air louvers and grills.

5.1.4 Segregation of hazardous and non-hazardous operations.

5. Plant Layout and Construction

5.1 Consideration of plant layout and construction in the design helps assure an optimum combination of employee protection, capital investment, and operating economy for all factors within the control of the designer. Layout based only on production or materials handling considerations may prove uneconomical when necessary exhaust or ventilation requirements are superimposed upon a layout not originally including such considerations.

5.1.1 Processes to be exhaust ventilated by a single LEV system should be located close together and arranged, if conditions permit, in order that:

(1) The shortest lengths of duct and minimum number of elbows are used.

(2) Proper proportioning of air flow from the various hoods is facilitated.

Scattered processes, or equipment operated infrequently, should normally be provided with separate exhaust systems.

5.1.2 Process equipment to be provided with a local exhaust system and the components of an exhaust system (e.g., hoods) should be arranged to permit the location of exhaust ductwork so as to:

(1) Permit the free operation of cranes, elevators, trucks, etc.

(2) Allow unobstructed accessibility to the ductwork for inspection, cleaning, and repairs.

(3) Provide maximum protection of ductwork from damage from the outside.

5.1.3 See Section 6 on Makeup Air Systems.

5.1.4 Hazardous operations should be segregated from non-hazardous work so far as practicable. In plants where most of the processes produce potentially harmful concentrations of air contaminants, it is preferable to isolate non-hazardous processes, e.g., place them in a separate building or room.

5.1.5 Location of air cleaning equipment.

5.1.5 Building design should make possible the location of air cleaning equipment so as to:

(1) Permit safe and unobstructed access for maintenance (e.g., filter or collection media removal, cleaning, or electrostatic precipitator servicing) and repair of air-cleaning equipment.

(2) Permit easy removal of dust or other collected material without creating a nuisance, health hazard, or a materials handling problem.

(3) Allow for cleaning and repairing the apparatus without contaminating general plant air.

(4) Protect wet collection systems and associated piping from freezing.

If the air cleaning equipment handles explosive or highly flammable gases or contaminants, the User should also consider the following provisions: it should be located outside or otherwise isolated; provided with pressure relief panels and safety barriers; provided with explosion suppression; adequately protected from lightning; and electrically grounded. Such precautions may be minimized for systems in which sufficient dilution air is handled to keep contaminant concentrations below 10-25% of the lower explosive limit for gases and vapors and 20% of the minimum explosible concentration (MEC) for dusts (except during reverse jet air cleaning of fabric filters when transient and instantaneous dust concentrations may exceed the MEC), and provided that adequate safety controls are installed to prevent mis-operation. (See Appendix)

Designers and users of LEV systems should also be cognizant of long-term plans for the site, adjacent buildings and their usages, and nearby geographical features.

5.2 Buildings shall be suitably adapted for hazardous operations and shall meet local building and fire codes related to LEV systems.

5.2 Generators, tanks, and other equipment in which toxic or explosive gases and volatile (either at normal or operating temperature) liquids are handled should not be housed in cellars or pits, for example. Explosion vents should be provided as required by codes of the National Fire Protection Association and/or the local fire authority having jurisdiction.

Fire curtains should be provided as required by codes of the National Fire Protection Association and the local authority having jurisdiction.

Roof vents for automatically venting smoke and products of combustion in event of fire should be provided as required by codes of the National Fire Protection Association and by local or state fire codes.

5.3 LEV system components shall be designed and constructed to provide easy cleaning and draining.

5.3. See references in Appendix A for more information on minimizing the effects of condensation of materials in the ductwork.

5.4 Where tools, processes, or equipment generate different dusts, fumes, or vapors that will, when intermixed, result in a health or explosion hazard, or destructive corrosion, such air contaminants shall be exhausted by separate exhaust ventilation systems.

5.4 It is the common practice in the semiconductor industry, for example, to provide separate LEV systems for air containing acids/corrosives and solvent vapors; labs routinely separate acids and cyanides.

This requirement assumes dusts, fumes, and vapors will be at sufficient concentrations in the exhaust air to create a health, explosion, or corrosive hazard. Destructive corrosion implies failure of duct, fitting, fan, or air cleaners.

5.5 LEV systems handling radioactive materials shall refer to Nuclear Regulatory Commission (NRC) requirements, or to other appropriate agencies for guidance.

5.5 Other appropriate agencies include, for example, the Department of Energy, or “Agreement State” provisions where a state agency has authority to regulate certain uses of radioactive materials within the state. (See Appendix)

6. Makeup Air Systems

6.1 Air exhausted through a local exhaust ventilation system shall be replaced.

6.2. Where applicable, the designer or User shall determine the appropriate static pressure relationship between the exhausted space and adjacent spaces and provide makeup air volumes accordingly.

6. Makeup Air Systems

6.1 Provision should be made for the supply of clean, tempered air into the building to replace air removed by LEV systems.

In most cases, makeup air should be provided by a dedicated mechanical ventilation system. There are cases where natural ventilation can be the source of makeup air, (e.g. in temperate climates with fresh outdoor air easily available, where the operation is outdoors, where the equipment is open to the atmosphere, and so forth). The designer should justify and document the rationale for the use of natural ventilation and how to assure reliable air delivery, e.g., what happens if the natural ventilation is blocked. (See Appendix)

6.2 The volume flowrate of makeup air is often equal to the exhaust volume flowrate. However, in some circumstances a slight negative pressure may be required in an area to control fugitive emissions and/or prevent migration of contaminants to other areas of the plant or building, or a slight positive pressure may be required to prevent intrusion of dust into clean areas.

Building air balance approaches may also be used to provide appropriate pressure differentials. When specifying the size of a makeup air system, future needs should also be considered. (See Appendix)

6.3 The designer or User shall optimize supply-to-exhaust-system airflow patterns in the space.

6.3 Where possible, the makeup air system should be located so as to maintain the following conditions:

(1) The supply air to the space should be located so clean, properly tempered air is first passed over the workers and then to the contaminated area, where it will be removed by the LEV system.

(2) The air flow should provide cross ventilation in the area, thus using this air for effective general ventilation as well as for makeup.

(3) The air should flow from the clean areas to contaminated areas.

(4) Avoid high velocities at worker locations to avoid vortices around a worker's body which can create higher exposures.

6.4 Recirculated air from a local exhaust ventilation system shall meet the requirements of ANSI/AIHA® Z9.7.

6.4 Recirculated air from LEV systems is not normally considered part of the makeup air system. Refer to the latest version of the Z9.7 standard that provides stringent requirements to be met before LEV air can be recirculated.

6.5 Makeup air delivery shall not reduce the performance of the local exhaust ventilation system.

6.5 Supply air locations and velocities should be selected to avoid high velocity drafts on hooded processes or on the workers. (See Appendix)

6.6 The intake for the makeup air system shall be so located as to protect against the uptake of contaminants from exhaust systems, process vents, or other contaminant sources.

6.6 See Section 8 for more information on standards of good practice for stack design and placement. Complete prevention of re-entrainment of exhaust air is not possible; this provision is intended to reduce re-entrainment to a minimum.

6.7 Makeup air shall be filtered at the air intake to protect ventilation system equipment.

6.7 This provision applies primarily to mechanical makeup air systems. It may or may not be valid for natural makeup air systems, e.g., where makeup air is provided through louvers in the wall, open doors, etc. The User should determine the need for filtration in natural makeup air systems. Typical filters to protect fans and coils include ASHRAE 52.1 ratings of 30–90% and ASHRAE 52.2 MERV ratings of 4–10.

6.8 Makeup air units shall be designed and operated to supply appropriate air volume flowrates at all times.

6.8 Where LEV systems vary the exhaust airflow over time, makeup air volume flowrates should track exhaust air flowrates to maintain proper pressure relationships in the space.

6.9 A monitoring system shall be provided which signals a malfunction of the makeup air system when the malfunction can adversely affect the performance of the LEV system.

6.9 Such monitors normally include pressure or flow monitoring devices.

6.10. Makeup air shall be clean.

6.10 The designer or User should document the selection of the "clean" air source. Previous definitions of "clean" air have included, "Air that meets air quality standards such as the EPA NAAQS." Clean air normally suggests "fresh outside air." However; "clean" air may also be obtained in some cases from hallways, warehouses, and other uncontaminated spaces.

6.11 When makeup air is used to provide thermal comfort for workers, the system shall be designed and operated in accordance with appropriate standards.

6.11 Tempering air for thermal comfort implies air heated or cooled to meet the needs of occupants of the space. Local building codes, ASHRAE 55–Thermal Environmental Conditions for Human Occupancy, ASHRAE 62.1–Ventilation for Acceptable Indoor Air Quality, and the AIHA publication Heating and Cooling for Man in Industry can provide guidance.

6.12 Where makeup air is heated by a direct-fired heater, the following provisions shall be met:

- Combustion products do not create airborne concentrations in the supply air in excess of acceptable concentrations selected by the User but never to exceed published OELs.
- Provision is made by the User to assure safe operations.
- Applicable codes are complied with.
- Manufacturer recommendations are complied with.
- Corrosive or flammable materials do not come in contact with the flame.
- Building return air is not allowed to pass through the flame.

6.12 Direct-fired makeup air equipment, in which natural gas or liquefied petroleum gas (LPG) only is burned directly in the air stream, is sometimes used for tempering makeup air. The User should determine likely combustion products (e.g., CO, CO_2, NOx,) and select acceptable maximum concentrations in the supply air and in the worker's breathing zones, e.g., "[some percentage] of the PEL." (Many Users select 10% of the OEL as an in-house standard.) Where published OELs are not available, the User should consult with chemical suppliers, industrial hygienists, and MSDS forms.

Carbon monoxide detectors are commonly used to assure safe burning operation.

The following items should also be considered in the selection and operation of direct-fired heaters:

(1) The heater should not be subject to freezing problems.

(2) The delivered air temperature should be easily controlled by modulating the flame that usually has a turndown ratio from 25 to 1 to 45 to 1.

(3) Industrial installations should meet the requirements of the Factory Insurance Association (FIA), Factory Mutual Global (FM Global), or other equivalent standards. Generally, manual as well as automatic shutoff valves, gas pressure regulators, air flow switches, safety pilots, and high limit temperature controls are required.

(4) 100 percent outside air should be handled over the burner with air velocities based on the burner manufacturer's recommendations. This velocity is usually in the range of 2500 to 3000 ft/min (13 to 15 m/s).

(5) Burners may be either of the raw gas or premixed type.

(6) When outdoor air is subject to being dusty or dirty, it should be filtered before it reaches the premix burner.

(7) Direct fired units generate carbon monoxide, water and other products of combustion. When burners and controls are properly selected, installed and maintained, these products of combustion should not constitute a problem. The User should provide adequate access for testing, cleaning and maintenance.

(8) During design and before installation, applicable codes and standards of the authority having jurisdiction should be consulted.

The User should be aware of the potential problems of dirt and dust, gas and vapor-laden air passing through the burner and, if such a problem is possible, take steps to control the hazard.

The User should note that Standard requirements refer to direct-fired heaters using natural gas and LPG only. Use of other fuels

6.13 Makeup air shall not be used as push air in a push-pull LEV system.

7. Exhaust Hoods

7.1 Exhaust hoods shall be selected, designed, constructed, operated, and maintained to provide control of routine and anticipated chemical or particulate emissions.

7.2 Exhaust hood design, construction, and operation shall consider and document the following factors:

- Inertial and kinetic effects of air contaminants and emission sources;
- Specific gravity effects of gas and vapor contaminants;
- Wake effects of air entering the hood and flowing past persons standing near the hood;
- Positioning of employees and equipment in the vicinity of the hood;
- Capture and control velocities;
- Air motion in the vicinity of the hood;
- Employee work practices;
- Thermal behavior of air contaminants; and
- Toxicity and hazardous properties of air contaminants.

should normally be avoided. Where free-standing kerosene units are used, always follow safety precautions required by the manufacturer and local authorities.

6.13 A push-pull hood is normally equipped with a dedicated air supply system for the push jet of the hood. Because the jet usually entrains much more air than is “pushed” into the jet, the makeup air system must be capable of replacing that air entrained into the jet and “pulled” or exhausted through the hood.

7. Exhaust Hoods

7.1 No hood can provide 100% control of emissions at all times in all circumstances. The intent of this provision is to insure that the design and operation of the hood is sufficient to provide adequate protection of employees and others.

The User should determine the criteria for control. A typical User control criteria to be applied during routine operations might be documented as: “Concentrations of emitted contaminants in the workroom air should not routinely exceed 10% of the ACGIH® TLV® (Threshold Limit Value), or the odor threshold, whichever is less.”

7.2 When hood design and operation does not take these factors into consideration, successful emission and exposure control is unlikely.

Bulleted items are further discussed in the Appendix. (See Appendix)

7.3 Exhaust air flowrate selection shall be determined by capture, control, and containment requirements.

7.4 Exhaust hoods shall, to the maximum extent feasible, be selected, designed, constructed, installed, operated, and maintained to provide control of unplanned emissions or equipment failure emissions.

7.3 The air volume flowrate is a function of the capture or control velocity at the hood. This velocity is often the most critical parameter of the hood. It should always be based on emission control, system configuration, and containment performance requirements. Recommended air flowrates are found in the *Industrial Ventilation Manual*(6), appropriate ANSI, OSHA, and NIOSH standards, and in other publications. Where published recommendations are not available, flowrates can often be estimated from similar equipment or by using fundamental principles.

7.4 The intent of this Section is to encourage the User to adapt policies and select equipment to deal with unplanned but reasonably-foreseeable adverse events and failures of process equipment. A User policy for dealing with unplanned failures might state, for example: "During equipment failure, resulting exhaust air concentrations within the enclosure or exhaust ductwork should not exceed one-half of the published IDLH or [some percentage] of the Lower Explosive Limit (LEL) for the worst credible accident," or, "Airborne concentrations of emitted air contaminants in the workroom air should not exceed [some percentage] of the PEL or TLV® during the worst credible leak."

Risk assessment procedures should be used in the appraisal of potentially hazardous failures.

7.5 Hood performance monitoring devices or testing procedures shall be provided. A real-time hood performance monitor shall be provided if failed hood performance could result in hazardous conditions for persons using the hood; the performance monitor report or output shall be accessible to users of the hood.

7.5 Compliance with this provision can be adapted to the needs of the User establishment. Compliance with this provision can also be tailored to the needs of the hood and equipment being monitored. Demonstrably equal or better approaches are acceptable.

The objectives of this provision are: (1) to help assure that hood performance is maintained over time, (2) to help assure the air flowrate at the hood is maintained at a safe flowrate, and (3) where failure of the hood could result in hazardous conditions, to provide a means for employees working at or near the hood to assure themselves the hood is working safely.

As it pertains to a real-time monitor, provision of reliable quantitative devices should be considered, e.g., static pressure taps with manometers at hoods and air cleaners, fan rpm monitors, motor amperage monitors, other airflow monitoring devices with or without alarms, or DDC systems with computer readouts, etc.

Users of the hood should be trained to read and interpret the output of any performance monitoring device or procedure in use. Users of the hood should be given instructions on what to do when a monitor suggests airflow, containment, or other performance measures have changed.

7.6 Selection of hood type shall be determined by the needs for hood performance.

7.6 Hood types must be selected to match the needs of the process, the emission source, air movement in the area, and work practices. For example, canopy hoods are often chosen for receiving hot rising air plumes, enclosing hoods are usually chosen for high-hazard operations, and so forth. See the Appendix for more guidance.

7.7 Hood design, placement, and operation shall ensure a uniform flow of air into the hood.

7.7 Airflow into the hood should be as evenly distributed as possible to assure consistent and reliable emission control. Slot and plenum hoods are commonly used to achieve uniform air flow distribution and capture velocity over long hood lengths such as would be required for plating tanks. Baffles and flanges can enhance airflow patterns. See the Appendix for more guidance.

7.8 Enclosing hoods shall enclose emission sources to the maximum extent possible. Capture hoods shall be placed as close to emission sources as possible.

7.8 A good enclosure has a number of benefits: It can reduce airflow requirements, increase control or hood face velocities, reduce costs, and improve containment performance. Where access requirements prohibit full enclosures, partial enclosures may be created with baffles and flanges. Baffles for minimizing cross drafts and hood flanges for increasing hood efficiencies are both important elements to be considered in hood design.

7.9 Hoods and connecting equipment shall be designed and operated to avoid fires and explosions.

7.9 An important design consideration for LEV systems that handle potentially explosible dusts and/or explosive vapors, or gases is provision of adequate exhaust rates to prevent the production of explosive mixtures within the LEV system. If the volume of contaminant evolved per unit time is known, the exhaust rate needed to dilute the contaminant to a point well below the lower explosive limit (LEL) or minimum explosible concentration (MEC) for the contaminant-air mixture can be calculated readily using equations found in the references. The User should establish policy, e.g., “The exhaust rate should be such that the concentration of contaminant is less than 10% of the lower explosive limit.”

Insurance companies and fire codes specify minimum exhaust volumes for ovens and other potentially hazardous operations. (See Appendix)

7.10 Hood design, operation, and testing shall consider and document the following parameters:

- Shape and construction material;
- The air flowrate necessary to control emissions and odor migration;
- The entry loss factors for hoods, slots and ducts, and/or the Coefficients of Entry, Ce;
- Velocities (e.g., face velocity, control velocity, capture velocity, slot and plenum velocities, and duct transport velocity); and
- Slot dimensions, slot velocities.

7.11 Manufacturers and suppliers of prebuilt hoods and exhausted tools/enclosures shall make available the following information regarding the manufactured hood to the designer and User: (1) the Coefficient of Entry (Ce) and/or the Loss Factor for the hood under desired operating conditions; (2) the actual volume flowrate required for optimum performance under the conditions of operation; (3) the hood static pressure required to generate the appropriate flow; (4) performance test descriptions and test results which prove hood performance; and (5) other appropriate physical parameters (e.g., damper positions, slot widths) to achieve optimum performance.

7.10 Hood technical data is found in the literature sources of Appendix A. Most hoods have already been built and the design data published elsewhere. One traditional source is the *Industrial Ventilation Manual*[6], which contains plans and specifications for over 200 different hoods. NIOSH and OSHA have also published data on hood design.

7.11 Designers and users require these data to properly design, operate, test, and maintain an LEV system.

The purpose of Item (1) is to provide data, which system designers can use to estimate static pressure requirements at the hood.

Although manufacturers cannot control the actual use of the hood over its lifetime, they can suggest appropriate parameters for optimum performance under defined operating conditions.

7.12 Before routine use begins, exhaust hood performance shall be tested to assure contaminant capture, control and containment performance meets the User requirements.

7.12 Performance is defined by the function of the hood, e.g., a capture hood's ability to capture contaminants, an enclosing hood's ability to contain the contaminant, some minimum air volume flow rate, some minimum static pressure, employee exposure protection.

Existing hood performance tests (e.g., ASHRAE 110, SEMI F15) or those recommended by the hood manufacturer can be adapted to the needs of the User. For example, the User may require a laboratory exhaust hood to meet ASHRAE 110 standards to provide a "Protection Factor, PF = 10,000," or some other in-house criteria. (See Appendix A, Sections 7.6 and 14.5 for more information on the PF approach.) Manufacturers and suppliers of hoods should document testing to whatever performance criteria are selected. Such performance testing may also take into account other performance measures (e.g., particle generation, product protection.) See the Appendix for more guidance. (See Appendix).

8. Ductwork and Stacks

8. Ductwork and Stacks

This section also includes the ductwork and stack on the downstream side of the fan and, where applicable, the makeup air ductwork. The purpose of the exhaust ductwork is to provide a conduit for the flow of air, in the desired quantities and at the desired velocities, from each exhaust hood to the point of discharge. Detailed duct design and application criteria is found in the *Industrial Ventilation Manual*(6) and other references in Appendix A.

8.1 LEV duct design shall be performed by those properly trained and educated.

8.1 This would include licensed mechanical engineers and/or certified industrial hygienists with appropriate training and experience in the design of LEV systems.

8.2 Static pressure losses shall be estimated throughout the duct system.

8.2 Static pressure is directly related to system performance and is useful during operation, testing, and maintenance. The designer should normally estimate (calculate or determine) static pressure losses before construction or procurement begins. This provision does not preclude the use of other design methods, which use, for example, total pressure instead of static pressure. (See Appendix)

8.3 Duct systems shall be designed using recognized and appropriate design approaches and procedures.

8.3 A balanced design, for example, usually provides for the most effective LEV system. Damper-balanced and plenum system designs may also be used, as appropriate. The intent of this provision is to assure that prior to construction and installation, LEV systems are designed following recognized approaches, guidelines and standards. (See Section 2 and Appendix Sections 2 and 8.3.)

8.4 Duct materials shall be chosen to be compatible with air contaminants exhausted.

8.4 Recommended general specifications are discussed in Section 12, Commissioning.

The User should consider the possibility of static electricity buildup when mixed particles, e.g., metal and non-metal, are being transported in ductwork or collected in the LEV system. Plastic pipe held by metal brackets and transporting metal particles, for example, may form a de facto capacitor capable of accumulating and discharging electrostatic charges.

Appropriate materials approved for use by cognizant authorities, e.g., SMACNA and others, should be used. Rarely, for example, would a PVC sewer pipe be appropriate.

8.5 Duct velocities shall be sufficient to prevent the settling of dry aerosols. Where mists, sticky particles, or condensing materials are carried in the duct, provision for duct cleaning shall be provided.

8.5 Air containing dry particles can be moved at a velocity sufficient to "scour" or transport particles through the ductwork because of the turbulence of the transporter air. Velocities of 3,000 to 5,000 ft/min (15–25 m/s) are common. Duct cleaning provisions usually include: drains, sloped ductwork to drains, cleanout openings, water spray cleaning systems, vacuum cleaning systems, and so forth.

Non-condensable vapors and gases mix intimately with the air and may be moved at any convenient velocity, determined by economy of duct sizes and power consumption. Common practice is to design such duct work for a velocity of approximately 1,200 to 3,000 ft/min (6–10 m/s) where only gases or vapors or both are exhausted.

When condensable vapors are to be exhausted, the designer should consider the effects of cold temperatures on the exhaust duct and make provision to prevent unwanted or uncontrolled condensation. If condensation nuclei are also present in the exhausted air/vapor mixture, this consideration is even more important.

When transport velocities are employed, the User should be aware of the potential for noise problems in the workplace and take measures to abate the noise or provide hearing protection for workers.

8.6 Round ducts shall be used in local exhaust ventilation systems on the upstream side of the fan or air exhauster.

8.6 Round ductwork has these advantages:

- It resists settling of dry particles;
- It is less expensive; and
- It resists collapsing.

Typical exceptions to this requirement may include the use of oval ductwork in tight spaces, square ductwork used in large plenum systems, and in transitions. The User should document any deviation from the requirements.

8.7 When it is necessary to carry exhaust ducts through fire walls, automatic dampers shall be provided in the exhaust duct in accordance with local and NFPA codes.

8.7 See Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists and Noncombustible Particulates, ANSI/NFPA 91-1999. In certain industries, similar restrictions apply to the passage of ducts through floors. This provision does not apply when it conflicts with ANSI/NFPA 45–2000 Para. 6–10.3.[3]

8.8 Stacks shall be located and designed such that (1) re-entrainment of exhausted air is held to a minimum and (2) workers in the vicinity of the stack are not exposed to hazardous concentrations of exhausted contaminants.

8.8 Some re-entrainment of exhaust air almost always occurs in any building that has both intakes and exhausts. The amount re-entrained will vary depending on exhaust volume flowrates, wind speed and direction, temperatures, locations of intakes and exhausts, and stack heights. Such User-defined goals as, “less than 1% re-entrainment in the source building or adjacent buildings,” or “avoid any odor complaints within the building,” or “workers not exposed to concentrations greater than 10% of the OEL,” are typical of such goals.. Users of this Guideline can select appropriate performance criteria and goals which meet the User’s needs

8.9 LEV stack outlets shall be sufficiently above adjacent air intakes or roof lines if they are within re-entrainment distance.

8.9 and 8.10 A widely-used rule of thumb is to place stacks at least fifty feet from air intakes, if possible; ten feet above adjacent roof lines and/or air intakes if within fifty feet, and to provide a stack exit velocity of at least 3,000 ft/min to avoid backdrafting. (See Section 8.10.) This is a reasonable rule, but it will not guarantee freedom from re-entrainment and each stack should be designed and built to meet the needs of the situation. Dispersion modeling can be another useful tool when designing stacks. See ASHRAE Fundamentals[2], for more definitive measures and design guidance.

Some communities require architectural enclosures and screens around ventilation equipment on the roof, and limit the height of stacks. In this case, special care should be taken to avoid re-entrainment. Some common rules of thumb include:

- Do not place air intakes and exhaust stacks in the same enclosure
- Separate the intake and the exhaust as far as possible.
- Use open enclosures (e.g., slatted sides).
- Use high-velocity stacks (e.g., 3000 fpm or higher) to “blow” the exhaust out of the enclosure.

8.10 LEV stack outlet velocities shall be selected to protect against backdrafting.

8.10 Backdrafting occurs when wind turns the plume over before it has a chance to fully escape the stack. The plume then may follow the stack down and reduce the effective stack height and dispersion.

8.11 Flexible vibration isolators on fan inlet ductwork shall be mounted on the outside of the exhaust ducts.

8.11 When mounted on the inside of the duct, the isolater may be pushed (sucked) into the airstream creating a barrier to air flow.

9. Air Cleaning Equipment

9.1 LEV systems shall be built, operated, and/or modified after obtaining the appropriate emissions and/or air pollution permits required by local authorities.

9. Air Cleaning Equipment

9.1 Air cleaning should be used to meet one or more of the following objectives:

- To meet permit requirements.
- To prevent the creation of a hazard or nuisance in the area exposed to the effluent of the LEV system.
- To prevent contamination of the plant makeup air.
- To protect fans or other air moving equipment.
- To permit recirculation of the exhausted air, under certain circumstances, in order to reduce heating or cooling losses.

Another type of separator is intended to recover valuable materials that may be present in the exhausted air. This section does not cover such product separators.

In recent years, most air cleaning equipment has been a function of the permit or emission limits required by local, state, and/or national air pollution control authorities. In most jurisdictions, one must obtain a permit modification from the local air pollution control agency any time a new stack is installed, or if older exhaust equipment is modified. (See Appendix)

9.2 Cleaning equipment selection and placement shall be determined by the air contaminant to be separated from the exhaust air.

9.2 Different air stream contaminants require different air cleaning devices, because of the nature of the contaminant itself. Each contaminant should be investigated to determine the most effective cleaning methodology. Each type of air cleaning medium has different characteristics. The efficiency of commercially available dust cleaning devices, for example, is commonly expressed as a percent of the weight of the entering contaminant retained by particle size. Such data should be interpreted with caution, since it is the amount, or concentration of material passing through, or both, that determines whether or not the device is operating in a satisfactory manner. Normally, the air cleaner should be placed and operated under negative static pressure to minimize leakage of contaminated air from the exhaust system. This suggests placing the air cleaner upstream of the exhaust fan.

9.3 The User shall establish and operate testing and maintenance programs to assure reliable and consistent operation of the cleaning equipment.

9.3 Emission rate, capacity, and resistance of the air cleaner should remain as constant as possible throughout its daily operating cycle and be nearly independent of entering dust, fume, or vapor concentration. The routine operation of the air cleaning equipment should not require shutdown during normal operation. Maintenance procedures should follow manufacturers recommendations. Maintenance that requires the entry of a worker into enclosed sections of an air cleaner should follow procedures for entry into a confined space, or into a permit-required confined space (if so classified), with appropriate control of exposures and hazardous energy sources and checks for low oxygen concentrations. (See Appendix)

9.4 Handling, transport, and disposal of effluents and collected materials from the air cleaning equipment shall meet Federal, State, and local regulations and shall not create a hazard to employees handling the materials.

9.4 Collected materials should be in such form or condition as to facilitate safe disposal or re-use. Sometimes two or more cleaning/collection systems are required for a process.

Federal hazardous waste regulations (RCRA – Resource Conservation and Recovery Act), transportation requirements (DOT – U.S. Department of Transportation), and local codes and requirements may impact handling, transportation, and disposal of these materials.

10. Fans and Air Moving Devices

10. Fans and Air Moving Devices

The term fan, as it is used in this section, refers to any device used to create the required flow of air in an LEV system: (1) fan, (2) some types of air compressors, (3) positive displacement blower, or (4) ejector. The most common air mover is the fan.

10.1 The following data shall be determined and documented prior to the final selection of a fan or air mover:

- Air flowrate;
- Fan total pressure and/or fan static pressure;
- Air temperature, humidity, and density;
- Aerosol or vapor loading;
- Type and size of fan;
- Inlet and outlet duct configurations;
- Wheel type, construction, and material;
- Motor size, type, drive starter wiring;
- Fan class and physical configuration of the fan housing;
- Access to fan housing, bearings, seals;
- Flexible couplings to ductwork;
- Noise and noise requirements;
- Mounting and vibration isolation;
- Rain and weather protection;
- Stack requirements; and
- Fan location.

10.1 It is important to select the proper type and size of fan for any installation. The major criteria listed are important for optimizing emission control, employee protection, efficiency of operation, first cost and operating costs, and maintenance and testing of the fan.

The preferred location for an exhaust fan is outdoors, normally on the roof. A properly ventilated penthouse can be provided to protect the fan and workers from the weather.

Fan location should be chosen such that noise is not a problem.

10.2 Fan selection shall consider possible system effect losses.

10.2 Not identifying and correcting for system effect losses may result in reduced flow at the hood. See AMCA 410, Recommended Safety Practices for Users and Installers of Industrial and Commercial Fans; AMCA 99, Standards Handbook; AMCA 803, Industrial Process Fans: Site Performance Test Standard; AMCA 200, Air Systems; AMCA 201, Fans and Systems; AMCA 202, Troubleshooting; AMCA 203, Field Performance Measurement of Fan Systems and ACGIH® Ventilation Manual in Appendix for more information. (See Appendix)

10.3 Fans shall normally be chosen such that the System Operating Point (SOP) lies on a steep part of the forward part of the fan curve.

10.3 This rule applies only to local exhaust ventilation systems. Selection of the SOP on a steep part of the forward part of the fan curve helps assure a reasonably constant volume flowrate at the hood when system static pressures vary from design, e.g., should the air cleaner losses increase, should design underestimate static pressure losses, should duct friction losses increase from settled particles, and so forth. This point is not usually the most efficient operating point, however.

Exceptions to this normal rule include manifold exhaust systems designed for variable inlets where operating on the flat part of the curve may be more advantageous, e.g. and blowers and compressors which operate at static pressures above 20 inches w.g.

10.4 The User shall develop safe operating and maintenance (O&M) procedures and install appropriate guards to assure safe use, operation, and maintenance of fans.

10.5 Fan selection shall consider long-term air contaminant effects on the fan and fan wheel.

10.5 This might include corrosion, buildup of material, or impact damage. Where severe conditions of abrasion or corrosion are present, special linings or metals can be used in fan construction and materials. Fan blades may need to be cleaned periodically.

10.6 Fans serving dust-collecting and corrosive vapor LEV systems shall be located on the clean-air side of the air cleaning device.

10.6 This will minimize corrosion and damage and assure continued satisfactory service. Where the design requires the fan to be on the upstream side, or where this requirement is impossible to meet (due to equipment limitations and so forth), provisions must be made for periodic inspection and cleaning, repairing, or replacement of the fan.

10.7 Safe means shall be provided to allow the wheel of an exhaust fan to be examined without removing connecting ducts.

10.7 This provision may be waived for smaller fans used in non-corrosive and non-dusty atmospheres, or with smaller wheels fans used in scale cabinets. The User should document any exceptions to this provision.

Access and cleanout doors should be closed before reactivating the fan. A lockout/tagout program should be used to safeguard maintenance personnel working on fans.

Where fan wheels are removable, means should be provided to allow the wheel of a fan to be removed from its casing without removing more than one inlet draw-band or flanged inlet section of duct, for centrifugal fans; or two such connections for tube-axial or vane-axial fans.

10.8 Where flammable vapors, gases, or dusts are carried in the air stream, precautions shall be taken to protect against ignition in accordance with NFPA and local fire code requirements.

10.8 To avoid fires and explosions, the fan wheel, the casing, or both, can be made of non-sparking material and the motor should either be placed outside the combustible region or be of explosion-proof design. In some cases, gas-tight shaft seals and general gas-tight construction are required to prevent leaks of gas or a mixture of air. Electrical bonding and grounding should be installed when the system carries materials that can create sparks or fire and bonding interlocks and alarms should be used where appropriate.

10.9 Where wire mesh screen is used on the fan discharge, the screen opening shall be no smaller than necessary to prevent entry of birds or rodents.

10.9 Use of such screens is discouraged, but when used, screen openings should not be so small as to encourage plugging from the inside by lint or other materials carried by the air flow. Such screens must be periodically inspected and cleaned. Allowance should also be made for the static pressure loss across the screen.

10.10 Following installation, and after maintenance of the fan, the correct direction of rotation of the fan wheel shall be confirmed.

10.10 The correct rotation should be marked on the housing.

10.11 Fan power on/off switches and/or power disconnects shall be located within view of the fan.

10.11 This helps assure safe and adequate power shutdown and lockout during installation, maintenance and inspection. Refer to NEC 430-102 for details. Common practice is to install such equipment within view of the fan and no further than 50 feet away.

10.12 Where air leakage is possible, the outlet ductwork from a fan shall not run through occupied spaces.

10.12 This requirement usually implies locating the exhaust fan outside the building so that outlet ductwork under positive pressure does not leak contaminated air into the occupied work environment, or making sure that inside ductwork is airtight.

11. Management of LEV systems

11.1 The User shall develop management policies that support successful operation and performance of LEV systems.

11. Management of LEV systems

11.1 No exhaust system can be successfully designed, operated, or maintained without management involvement. The policy statement should typically contain the following items:

- Acceptance of a statement of responsibility;
- Identification or assignment of a cognizant or responsible person;
- Recordkeeping provisions;
- Maintenance of up-to-date plans and specifications;
- Development of emergency plans;
- Provisions for employee training;
- Provisions for ventilation testing and monitoring of LEV systems;
- Provisions for hood use approval mechanisms; and
- Provisions for rules-of-use, standard operating procedures, and work practices.

11.2 The User shall develop and enforce an LEV work practices program.

11.2 Optimum work practices should normally include:

- Sashes, doors, and exhausted enclosure or hood closures should be placed at the proper position.
- Hoods and exhausted enclosures should be used when the exhaust is on.
- Only approved materials should be used in the exhausted enclosure and hood.
- The employee should do only that for which he/she is trained.
- A worker should not place his or her body in the exhausted enclosure or hood.
- Employees should be trained to use proper work practices at the LEV system and in the safe and effective operation of the system.

11.3 The User shall develop an LEV maintenance program.

11.3 See Section 13 for detailed information.

11.4 The User shall establish and maintain an LEV testing and monitoring program appropriate to the hazard being controlled by the LEV system.

11.4 Testing and monitoring may be used, for example, to assure proper damper position and correct operation of linkage. Automatic fire dampers should not normally be used in enclosure and hood exhaust systems unless required by code. Appropriate records of testing and monitoring programs should be kept. Such recordkeeping often includes drawings (maintained up-to-date), specifications, testing and balancing reports, monitoring results, system usage records, training schedules, O&M records, and repair history.

12. Commissioning

12.1 The User shall use a commissioning approach to design, procure, install, construct, and accept LEV systems.

12.2 Local exhaust ventilation systems shall be constructed so they can be operated safely, economically, and maintained easily.

12.3 Materials of construction shall be compatible with the process and air contaminants to be exhausted.

12.4 Construction shall assure the continued effective operation of the LEV system over its expected lifetime.

12.5 System components shall be constructed to be airtight on the upstream side of the fan; system components shall be constructed to be airtight on the downstream side of the fan when such components are inside the building.

12.6 Ductwork shall be accessible for inspection and maintenance, and shall be protected against external damage.

12. Commissioning

12.1 Commissioning is a process in which a new or remodeled ventilation system performance is identified, specified, verified, and documented before construction begins to assure proper operation and compliance with codes, standards, and design intentions.

Commissioning normally requires testing and demonstrations to verify the system operates as designed prior to beneficial occupancy. The User should determine the appropriate degree to which a commissioning process is used. (See Appendix for additional information, esp. ASHRAE Guideline 1. The HVAC Commissioning Process.)

12.3 Ducts may be made of metal, plastic, ceramic, tile, fiber, concrete, or other material having a smooth interior finish and suitable corrosion and erosion resistance for the intended service. The duct may be painted or coated to increase resistance to corrosion or abrasion.

For corrosive vapors, gases, or fumes, the ducts, hoods and air-moving equipment should be constructed of, or coated with, materials having suitable corrosion-resisting properties.

All hoods should be free from burrs or sharp edges and reinforced to maintain their shape when necessary.

12.4 Construction practices, which will help assure effective operation over the expected lifetime of the equipment, are included in the Appendix. (See Appendix)

12.5 Air tightness. Regardless of the construction method used, all components should be made airtight by welding, sealing or other equally effective methods. This provision refers to ductwork that runs through occupied spaces.

12.6 Positioning of cleanout doors and access openings should comply with SMACNA standards for industrial ducts.

12.7 The use of dampers and blast gates shall not be permitted in the main or submain ducts of an LEV system unless provided for the specific purpose of complete air shutoff, or for balancing airflow in the system. After adjustment, they shall be fixed in place to prevent unauthorized or accidental adjustments.

12.8 Where it is necessary to install motors, lights, switches, or fan controls in system atmospheres

12.9 No additional duct runs shall be added to an existing LEV system unless (1) such additions were specifically provided for in the original design or such additions are approved by a person qualified to perform system design, and (2) modifications to the existing LEV system can be made and not result in deteriorated performance of the existing LEV system.

12.10 Where failure of the exhaust equipment could result in airborne concentrations of contaminants at or above IDLH levels, the exhaust and supply air systems and the process machinery controls shall be interlocked so process machinery can operate only when the exhaust and supply systems are in operation.

13. Operation and Maintenance

13.1 The User shall establish and maintain a program of safe operating procedures.

13.2 Equipment that is a part of an LEV system shall be operated in accordance with the manufacturer's instructions.

13.3 Employees working with LEV systems shall be instructed on the proper operating method and the reasons for the installation and operating procedures.

13.4 No process or equipment on which an LEV system has been installed for employee protection or fire control shall be operated when the exhaust system is not functioning properly.

12.7 Spray painting the damper area is useful to quickly identify any changes to the system. In LEV systems handling abrasive dust, blast gate dampers are not recommended; where used, frequent inspection and maintenance will be required. It is not the intent of this section to preclude the use of automatic louver dampers or similar devices intended to close off openings to the outside when the system is not in operation. This provision also does not preclude the use of VAV approaches used in laboratory fume hood systems when allowed by ANSI/AIHA® Z9.5.

12.10 Other equipment needing interlock to process equipment may include the air moving device and the water supply where wet collectors requiring water flow for collection are used, and electrical bonding alarms when the system is so equipped. (See Appendix)

13. Operation and Maintenance

13.1 The User's program should be based on the needs of the system and the process.

13.2 This is especially important for hoods, air-cleaning equipment, and air moving devices.

13.3 Employees should be provided a periodic training program established by the user (e.g., annual training.)

13.4 Exceptions may occur during maintenance, emergencies, repairs, and when the process cannot be safely stopped. During such malfunctions, employees should be provided with alternative protection, e.g., respirators, as required to meet User and other requirements for protection.

13.5 Every LEV system handling particulate matter shall be operated with inlets to the system open unless the system was specifically designed for safe operation with some inlets closed.

13.5 An example is a floor sweep in a wood shop. Using dampers for any reason except balancing and shutoff during maintenance is normally discouraged. Operating a partially closed duct run reduces the air velocity and transport characteristics of the air and can lead to the deposition of materials in the ductwork.

13.6 LEV systems shall be maintained in good working order.

13.6 Continued acceptable performance of all LEV systems requires they be maintained in good condition throughout their lifetimes. Otherwise, employee exposure risks increase. A new LEV system should be inspected at least daily until a maintenance schedule is established.

13.7 Maintenance personnel responsible for LEV systems shall be instructed on its proper operation and the reason for the installation.

13.8 Maintenance personnel responsible for an LEV system shall be trained to "troubleshoot" the system in the event of malfunction.

13.9 The User shall establish a program of preventive and scheduled maintenance.

13.9 In order that an LEV system performs its designed functions, preventive and scheduled maintenance is necessary. The program should be tailored to the needs of the system. (See Appendix)

13.10 Manufacturers' recommendations for the maintenance of LEV system components shall be included in the maintenance schedule.

13.10 In the absence of manufacturer instructions, refer to the Appendix, "Industrial Ventilation Maintenance Check Lists," for typical maintenance scheduling guidance.

13.11 The User shall establish and support a program to keep maintenance records appropriate to the hazard being controlled by the LEV system.

13.11 It is often useful to keep a log book of maintenance services and dates at or near the ventilation system. The responsibility for scheduled maintenance and oversight should rest with a single individual who should also see that adequate records are maintained.

13.12 Drawings, plans and specifications shall be kept up-to-date as LEV systems change.

13.12 Every person testing, maintaining and redesigning an LEV system should have access to and be familiar with the most recently updated plans and specifications for the LEV system.

13.13 The user shall establish and comply with lock-out, tag-out programs for both the electrical power sources and mechanical energy sources.

13.13 Where feasible, the fan wheel itself should be disabled or locked out during installation and maintenance of the fan. This will preclude extraneous static pressures in the system (e.g., from other fans) from causing the fan to turn.

14. Testing, Balancing, and Operational Checks

14.1 Performance standards and operating criteria shall be established by the User for every component of an LEV system.

14.2 The User shall select test methods and test instruments appropriate to measure the established performance criteria of Section 14.1.

14.3 After construction or major modification, the LEV system shall be tested before routine service begins to assure the system meets the established performance criteria of Section 14.1.

14. Testing, Balancing, and Operational Checks

14.1 After an LEV system is installed, it needs to be tested to make certain that it performs according to design or operating performance criteria, normally established before installation and during the commissioning process. Performance criteria (e.g., “The flowrate should be 1,000 scfm; the hood static pressure should be 0.75 inch w.g.”) are useful because testing and measurements can then confirm satisfactory performance of the LEV system. Major LEV components to be tested should usually include the hood or exhausted tool or enclosure, the air cleaner, and the fan. Performance criteria usually includes such parameters as: hood static pressure, minimum air volume flowrate, average, minimum, and maximum hood face velocities, visual containment, measured containment performance factors, capture velocity, slot velocity, ASHRAE 110 ratings, SEMI F15 requirements, transport velocity, pressure drop across air cleaners, fan total pressure, motor amperage, and so forth, as appropriate.

14.2 These may include some version of the ASHRAE 110 test method, the SEMI S6 (Appendix) test protocol, containment tests using smoke or vapor, face and duct velocity measurement protocols, various ACGIH® *Industrial Ventilation Manual*[6] testing procedures, and hood static pressure. Such methods should be tailored to the needs of the LEV system by the User.

14.3 Such tests may be performed at the manufacturer s facilities and/or at the site after installation but before routine use begins.

14.4 The LEV system shall be periodically tested and monitored in accordance with a schedule determined by the User.

14.4 Periodic testing programs should be established by the User for every LEV system. Objectives of testing normally include:

- Determination of the effectiveness of the ventilation system (emissions capture, particulate transport, employee and product protection, efficiency, air cleaning.)
- Establishment of baseline or startup conditions.
- Monitoring of conditions throughout the life of the system.
- Compliance with permitting agency requirements and management-determined performance criteria.

14.5 The hood shall capture, receive, or contain air contaminants at some specified performance criteria established by the User.

14.5 For example, "no visible emissions," "PF = 8,000," "99.999% containment," "meets SEMI F6 (Appendix for LEV systems)," "meets ASHRAE 110 at AM 0.05," etc. Not specifying hood performance makes it difficult to test and increases the uncertainty of employee exposure protection.

14.6 Qualitative and/or quantitative tests shall be adopted by the User to assure hood capture and containment performance.

14.6 The User should establish a program depending on needs and resources. See Appendix for more information. (See Appendix)

14.7 Each LEV system shall be tested (and balanced when appropriate) during the Commissioning process and thereafter on a schedule determined by the User.

14.7 See Section 12 for information on Commissioning.

14.8 Persons performing testing and balancing shall be qualified by training, experience, or certification to perform the work.

14.8 Such services should normally be performed by certified testing adjusting and balancing (TAB) professionals, certified industrial hygienists, trained engineers, or by suitably trained technicians under their direct supervision. TAB professionals usually do not have the ability to determine if the system actually controls the hazard, which is usually under the jurisdiction of a certified OH&S professional. Some TAB firms are more familiar with heating air conditioning and ventilating (HVAC) systems for residential and commercial facilities, so it is good practice to determine if the firm has industrial ventilation experience before engaging them to test an LEV system.

14.9 Testing instrumentation shall be suitable for the measurements to be taken.

14.9 For example, velocity pressure measurements should normally be obtained using a pitot tube and manometer or other calibrated pressuring-measuring device; velocity measurements with a velometer; and humidity with a psychrometer, etc.

14.10. Testing instruments shall be calibrated in accordance with manufacturers recommendations, or more often if specified by the User.

14.10. Calibration should follow, as a minimum, equipment manufacturers recommendations and methods. Circumstances may require more frequent s recommended field calibration if so determined by the User. Use manufacturer methods to zero the instrument. Corrections for air density are required in pressure-actuated instruments. Periodic factory calibrations should be made at intervals by the manufacturer.

14.11 Records of testing and balancing shall be maintained by the User.

14.12 Makeup or replacement air systems shall be included in any LEV testing protocol.

14.12 Because naturally or mechanically supplied air must be provided to the workspace, testing should be used to verify performance of the makeup air system, with adjustments for flow, direction, and supply air system components commonly found in HVAC systems, such as coils, burners, chillers, dehumidifiers, diffusers, etc.

14.13. Testing and monitoring equipment shall be safe for the intended use.

14.13 For example, some measuring devices contain heated elements; in this case the User should determine if the instrument is intrinsically safe before using it in a combustible, flammable or explosive location.

14.14 System testing results shall be made available to those with a need to know.

14.14 The User should determine who has a need to know and what training is required so recipients of such information will be able to understand the information provided. Workers at the hood, for example, should be trained to understand basic flow parameters, e.g., flowrate, pressure, and how to read any real-time airflow monitor installed at the hood.

Appendices

These materials are not part of the standards requirements but provide supplementary information to explain or expand on requirements and recommendations.

An Audit Form is included in Appendix B.

Appendix A. Commentary on the Standard by Section Number

Section 1.4 Examples of air moving systems which are exclusively part of an industrial process include air conveying systems, the air supplied to a blast furnace, air used in a semiconductor wafer spin tool, or the air used to move products on a vibrating table.

Section 2. Source information for listed References are provided below:

(1)American Industrial Hygiene Association, 2700 Prosperity Ave, #250, Fairfax, VA 22031.

(2)American Society for Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.

(3)National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101.

(4)OSHA, 200 Constitution Ave, NW, Washington, DC 20210.

(5)(5a) The Department of the Air Force, Pentagon, Washington, DC 20330. Note: An older standard cited in this Standard, AFOSH Standard 161.2 was incorporated into AFOSH 48-8 and both were then superseded by Air Force Manual 48-155, 1 October 2008. See URL www.pdhealth.mil/downloads/AirForce_Manual_48-1 55.pdf.

(5b) National Institute for Building Sciences, 1090 Vermont Ave, NW Suite 700, Washington, DC 20005. See also the “Construction Criteria Base (CCB)” which is used by DOD, VA, GSA and other federal agencies for design specifications for welding, automotive processes, aircraft paint hangars, indoor firing ranges, laboratories, and kitchen ventilation systems. See URL www.wbdg.org/. In particular, see UFC 3-410-04N (October 25, 2004), “Industrial Ventilation Systems Design.” URL at www.wbdg.org/ccb/DOD/UFC/ufc. See also UFC 4-211-02NF, “Corrosion Control and Paint Finishing Hangars,” at same URL.

(6)American Conference of Governmental Industrial Hygienists, Inc., Kemper Woods Center, 1330 Kemper Meadows Drive, Cincinnati, OH 45240.

(7)SMACNA, 8224 Old Courthouse Road, Tysons Corner, Vienna, VA 22180.

(8)AMCA, 30 West University Drive, Arlington Heights, IL 60004.

(9)NAVFAC web page (www.NAVFAC.navy.mil).

Other Technical and Educational Resources:

The following technical resources provide additional guidance and education. Names and addresses are shown in C, below.

A. Standards, Guidelines, Criteria Documents, Position Statements (use Latest Version)

AGA: ANSI Z83 series, *Direct Gas-Fired Industrial Air Heaters*. ANSI Z21 series, Draft Hoods.

AGS: *Guideline for Gloveboxes*, about 100 pages; document describes various guidelines for the construction and use of glovebox hoods.

AMCA 410, *Recommended Safety Practices for Users and Installers of Industrial and Commercial Fans*; AMCA 99, *Standards Handbook*; AMCA 803, *Industrial Process Fans: Site Performance Test Standard*; AMCA 200, *Air Systems*; AMCA 201, *Fans and Systems*; AMCA 202, *Troubleshooting*; AMCA 203, *Field Performance Measurement of Fan Systems*.

ANSI: ANSI Z223.1, *National Fuel Gas Code*

ASHRAE; Four ASHRAE Handbooks: *Fundamentals, HVAC Systems and Equipment; Refrigeration*, and *HVAC Applications*; American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASME: ANSI/ASME B15.1 *Safety Standard for Mechanical Power Transmission Apparatus.*

EPA: *Standard Specification for Laboratory Fume Hoods.*

GSA: Federal Standard 209A-E, *Cleanroom and Work Station Requirements, Controlled Environment.*

NFPA: Contact NFPA (Address shown on next page). Use latest versions of all standards. NFPA 45 *Fire Protection for Laboratories using Chemicals* NFPA 30 *Flammable and Combustible Liquids Code*; NFPA 90A *Standard for the Installation of Air Conditioning and Ventilating Systems*; NFPA 91 *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists and Noncombustibles*; NFPA 69, *Explosion Prevention Systems*; NFPA 33, *Standard for Spray Operation Using Flammable or Combustible Materials*; and NFPA 58, *Storage and Handling of Liquefied Petroleum Gases*.

NRC: *Prudent Practices for Handling Hazardous Chemicals in Laboratories*, National Academy Press, Washington DC, see Section I.h, Laboratory Ventilation.

NSF: *National Sanitation Foundation Standard No. 49 for Class II Biohazard Cabinetry (Laminar Flow)*, Box 1468 Ann Arbor, MI 48105

OSHA: OSHA standards 1910.106, 107, 108, and 252 contain references to ventilation.

Occupational Safety and Health Administration

SEMI: SEMI S2 Environmental Health and Safety Guidelines for Semiconductor Manufacturing Equipment; SEMI S6 Safety Guideline for Ventilation.

SMACNA: *Accepted Industry Practice for Industrial Duct Construction*, 126 pages; *Rectangular Industrial Duct Construction Standards*, 136 pages, *Round Industrial Duct Construction Standards*, SMACNA, 296 pages; *Guide for Steel Stack Construction*, 102 pages, *HVAC Systems Testing, Adjusting, and Balancing*, about 250 pages.

USDHHS, *Biosafety in Microbiological and Biomedical Laboratories*, 1988, HHS Publ. No. (NIH) 88-8395; for sale by the USGPO, Washington, DC 20402.

B. Textbooks/Handbooks/Articles

ACGIH®, *Industrial Ventilation Manuals (2 volumes)*, 27th Edition, contact ACGIH®, 1330 Kemper Meadow Drive, Cincinnati, Ohio 45240; about 500 pages.

DiBerardinis, L. et.al., *Guidelines for Laboratory Design*, 2nd Edition, Wiley-Interscience, New York, NY, 1993; excellent book details fundamentals of laboratory design. (Note: 3rd edition published in 2001).

Burton, D. Jeff IVE, Inc., *Industrial Ventilation Workbook*, 6th Edition, 2010; IVE, Inc., 2974 Oakwood Drive, Bountiful, Utah 84010; 310 pages; also available from ACGIH®, AIHA®, ASHRAE, and ASSE.

Goodfellow, Howard D. *Advanced Design of Ventilation Systems for Contaminant Control*, Elsevier Publishers, NY, NY.

Hemeon, W.C.L., *Plant and Process Ventilation*, edited by D. Jeff Burton, 470 pages; CRC Press Inc, NY, NY.

C. Professional Organizations/Home Pages

AABC (Associated Air Balance Council; sets standards for TAB of ventilation systems)
1518 K St NW Suite 503, Washington, DC 20005

AGA (American Gas Association; direct-fired makeup air publications, hood design)
1515 Wilson Blvd., Arlington, VA 22209

ACGIH® (American Conference of Governmental Industrial Hygienists; publications, reports, IV committee activity, IV Manuals, journal) 1330 Kemper Meadows Drive, Cincinnati, OH 45240

AGS (American Glovebox Society; standards, educational materials)
2150 W. 29th Ave., Suite 310, Denver, Colorado 80211.

AIHA® (American Industrial Hygiene Association; journal, engineering committee, ANSI Z9 Secretariat, training courses)
3141 Fairview Park Drive, Suite 777, Falls Church, VA 22042.

AMCA (Air Movement and Control International Association; fans and dampers; numerous publications)
30 W. University Drive, Arlington Heights, Ill 60004

ANSI (American National Standards Institute; industrial ventilation standards)
Contact AIHA®, the secretariat.

ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers; numerous books, articles, standards; journal)
1791 Tullie Circle, NE, Atlanta, GA 30329

ASTM (American Society for Testing and Materials; standards and guidelines;
100 Barr Harbor Drive, West Conshohocken, PA 19428

CDC/Office of Biosafety (Centers of Disease Control; publications, information on biosafety cabinets)
Atlanta, Ga 30333

EPA (Environmental Protection Agency; publications)
Chief, FERPB, PM-215, Washington DC 20460.

NFPA (National Fire Protection Association; standards, publications)
1 Batterymarch Park, Quincy, Mass 02269

NIOSH (National Institute of Occupational Safety and Health; lists of publications, studies of laboratory health and safety, standards)
4646 Columbia Parkway, Cincinnati, Ohio 45226

NSF (National Sanitation Foundation; information on biosafety hoods)
Box 1468, Ann Arbor, MI 48105

NADCA (National Air Duct Cleaners Association; publications on duct cleaning, recommended standards for duct cleaning)
1518 K St NW Suite 503, Washington, DC 20005; tel 202-737-2926

NEBB (National Environmental Balancing Bureau; list of certified HVAC balancing firms, publications, standards and practice for TAB)
4201 LaFayette Center Drive, Chantilly, VA 22021; tel 703-803-2980

OSHA (Occupational Safety and Health Agency; regulations, publications)
201 Constitution Ave, NW, Washington DC 21210.

SMACNA (Sheet Metal and Air Conditioning National Association; publications, sheet metal, ductwork) 4201 Lafayette Center Drive, Chantilly, VA 22021

SEMI International (Semiconductor Equipment and Materials International; ventilation standards for the semiconductor industry) 3081 Zanker Road, San Jose, CA 95134.

Section 4.1. Designers should be able to competently perform such tasks as: select appropriate control strategies and LEV equipment, conduct duct layout and sizing, determine required capture and control velocities and air flow rates, select appropriate fans, and so forth. Operations personnel should be able to competently perform such tasks as: operate system function and monitor performance, deal with emergency operations and shutdown (e.g., fire, accident), conduct normal startup and shutdown, assess and make adjustments to the normal equipment SOPs, use lock out/tag out provisions, conduct routine trouble shooting, interpreting alarms and monitors for proper response, make visual inspections for safety and health concerns, and so forth. Maintenance personnel should be able to competently perform such tasks as: make mechanical and electrical diagnostics and repair, conduct preventative, scheduled and emergency maintenance, conduct trouble shooting, use lock out/tag out procedures, understand startup and shutdown provisions, safely make duct penetrations and hanger repairs, service alarms and other monitoring devices (e.g., Magnehelic gages), and so forth. Testing personnel should be able to competently perform such tasks as: conduct system testing and balancing, do non-destructive testing, conduct visual inspections, conduct appropriate hood and LEV testing, and so forth.

Section 4.2. Employee exposures do not occur in the industrial environment unless contaminants are emitted into the air somewhere in the workplace. Workroom air moves the contaminant into the breathing zone of the employee. The evaluation of these interrelated parameters is often called emission or problem characterization. No LEV system will operate at optimum performance unless these parameters are understood before design begins.

Section 5.1.5. It should be noted that NFPA 33, a fire standard for spray painting operations, traditionally allowed concentrations of 25% of the lower explosive limit for gases and vapors and 50% of the minimum explosible concentration for dusts.

Section 5.5. The NRC and others have adapted an “As Low As Reasonably Achievable” (ALARA) approach for LEV systems. When following this approach, system layout will typically provide for (as a minimum):

(1) Continuous remote measurement and indication of air flow;

(2) Access for radiation measurements and swipes for residual radioactivity;

(3) Access for preventive maintenance or replacement of installed filters and monitors;

(4) Prevention of recirculation of exhaust to occupied areas; and

(5) Sufficient airflow to reduce concentrations of radioactive materials to below the Derived Air Concentration (DAC) established by the regulatory authority (e.g., Nuclear Regulatory Commission, Department of Energy, or agreement state).

Section 6.1. Supplying makeup air is always necessary for one or more of the following reasons:

(1) To ensure exhaust hoods operate as designed. If the room is under negative pressure, the static pressure against which the exhaust fans operate will be increased and the volume flow correspondingly decreased. Some types of axial flow fans are particularly sensitive to changes in pressure.

(2) To ensure the proper operation of natural draft stacks, flues, and fuel burning appliances.

(3) To eliminate high velocity drafts through doors, windows, or cracks into the zone of influence of exhaust hoods.

(4) To eliminate cold drafts on workers.

(5) To eliminate additional dispersion of contaminants in the workroom by high velocity drafts (e.g., from accumulated dust on rafters).

(6) To prevent dust laden air in adjacent areas from being drawn into operating areas which must be kept clean for processing reasons.

(7) To avoid difficulty in opening or closing doors to room or building.

(8) To dilute low concentrations of airborne nuisance material that don't justify local exhaust systems, by being directed so as to flow through as much plant area as possible.

(9) To provide effective ventilation for the personnel, particularly in warm weather.

Section 6.2 Where a pressurized occupancy is desired, a common practice is to supply 10% more air than exhausted out of the building to minimize or eliminate infiltration from adjacent spaces or external walls. Similarly, in laboratories a common practice is to reduce supply air by 10% below exhaust volume flowrates to maintain a slight negative pressure in the lab. Pressure relationships between spaces are a critical element of the design process.

Section 6.5 Makeup air is introduced with an even distribution and flowing in the direction of the exhaust hood. Plenums with air discharge through perforated plates can be an excellent means of achieving even, low-velocity make-up air introduction. Air discharge openings have entirely different flow characteristics from suction openings. It is possible for the supply air to be "thrown" for considerable distances at high velocities. When high velocity supply outlets are used, they are located so objectionable drafts are not created in the occupied area. Under certain conditions diffusers could be used to reduce draft conditions. Details of air jet action are beyond the scope of this standard. See the ASHRAE Handbook-HVAC Systems and Equipment.[2]

Section 7.2 Hood Design information on bulleted items is provided below:

- Inertial Effects. Particulate contaminants will be projected into the air with the kinetic energy imparted to them at the time of their production or as applied later by the process. Such contaminants travel through the air until their kinetic energy is dissipated in overcoming air resistance. The distance traveled depends primarily upon the mass. Since particles of hygienic significance (usually 10 micrometers or less) gaseous contaminants (molecular state) have very small mass, their dispersion by kinetic energy is very limited. A 2-mm quartz particle having an initial velocity of 10,000 ft/m (50 m/s) will travel about 140 ft (43 meters) through still air before its energy has been dissipated. In such cases the hood needs to be constructed and positioned in a manner to physically enclose the contaminant generation point or to physically intercept the contaminant. A 10-micrometer quartz particle having the same initial velocity will have dissipated its energy after having traveled about 1.5 inches (38 mm). Contaminant particles smaller than 10 micrometers, fumes, vapors and gaseous contaminants will not have significant inertial effects, are truly airborne, following air currents and are not subject to appreciable motion either upward or downward. These materials will move slowly with respect to the air in which they are mixed. For these cases hoods should generate airflow patterns that will produce sufficient velocities to overcome the contaminant laden air plus extraneous air currents.
- Specific Gravity Effects. Frequently, the location of exhaust hoods for control of gasses and vapors is based on a supposition that the contaminant is "heavier than air" or "lighter than air." In most health hazard applications, this criterion is of little value because the density of such contaminant/air mixtures deviates very little from that of air. Normal air movement will assure an even mixture of these contaminants. Exception to these observations may occur with very hot or very cold operations or where a contaminant is generated at very high levels and control is achieved before the contaminant becomes diluted. It can also occur in a closed room with no air motion.

- Wake Effects and vortices. The objective of industrial ventilation is to control the worker's exposure to toxic airborne pollutants in a safe, reliable manner. As one of the main engineering controls, local exhaust ventilation is designed to be near the point of contaminant generation. Often, consideration is not given to how the workers will position themselves with respect to the air flow. As air flows around an object a phenomenon known as "boundary layer separation" occurs. This results in the formation of a turbulent wake on the downstream side of the object similar to what is observed as a ship moves through the water. The wake is a region of vigorous mixing and recirculation. If the object in question is a person who is working with, or close to, a contaminant generating source, recirculation of the contaminant into the breathing zone is likely. An important consideration in the design of ventilation for contaminant control is minimizing this wake around the human body and, to the extent possible, keeping contaminant sources out of these recirculating regions.
- Positioning. The position of the worker with respect to the flow direction effects breathing zone concentration. Immediately downstream of the worker a zone of reverse flow and turbulent mixing occurs due to boundary layer separation. Contaminant released into this region (e.g., from a hand-held or close source) will be mixed into the breathing zone resulting in exposure. Having the employee stand 90 degrees to the direction of flow is often more effective in reducing exposures.

Section 7.4 Hood static pressure is usually directly related to airflow through the hood. Static pressure taps, hoses, and manometers can be purchased for as little as $25.

Section 7.6 Many recommended hood configurations can be found in the *Industrial Ventilation Manual*[(6)] and other publications.

Three generic types of hoods have traditionally been recognized in industrial ventilation:

- The Enclosing hood. Examples are wet stations, glovebox hoods, lab hoods, bench hoods, grinder hoods, and others with four or more sides. Emissions are contained within the enclosure by air flow into the hood through the openings. Reasonably high inward velocities can be achieved with low air flows. The enclosing hood is preferred wherever the process configuration will permit. If complete enclosure is not possible partial enclosures should be used. A partial enclosure would be a laboratory hood or a paint booth where the inward flow of air into the enclosure through the opening contains the contaminant. The partial enclosure requires higher air flows to achieve sufficient control velocities.

The quantity of air required for enclosing or partially enclosing hoods is determined by two factors:

(1) The air velocity through all openings must be great enough to prevent the escape of contaminated air, and the air exhaust volume must be sufficient to carry away all air or gas introduced into or created within the enclosure. In the design of the hood, special attention must be paid to the fit around rotating shafts, etc. and to the selection of air volume so that there will be an adequate flow of air into the hood at these points.

(2) The velocity within the hood should not be high enough to carry away valuable products unless these are recovered later. In some applications the velocity in the enclosure need not be high enough to prevent settling; in this case, provision should be made for the easy removal of settled dust.

In general, enclosing hoods should not also enclose the worker, but should be interposed between the worker and his operation. If in some cases it is necessary also to enclose the worker, the worker will usually require extensive personal protective equipment, as for example in totally enclosed sand-blast rooms.

- The Capture hood. These are hoods with one to three sides. A welding snorkel-type hood is typical. Others include sidedraft and downdraft hoods. These types of hoods should be located as close as possible to the point of contaminant dispersal and should provide air flow in the direction from the worker to the contaminant source. Other names: active or external hoods.
- The Receiving hood. These hoods are designed to receive the emission source (which has some initial velocity imparted to it by the emitting source.) A canopy hood is a receiving hood because it receives hot rising air and gases. A small handheld tool hood may be equipped with a receiving hood. A push-pull hood is a receiving hood. The receiving hood should be positioned to take advantage of contaminant motion. For example, if the contaminant is emitted with significant velocity and if it contains large particles, such as grinding, the hood opening should be oriented in the path of the emission so as to utilize the directional tendency of the motion of the contaminated air for its own capture. Other names: passive hoods, exterior hoods.

Other general hood classifications of more recent origin include:

- Primary exhausted enclosures or hoods; Examples include wet benches, solvent hoods, diffusion furnace scavenger exhaust hoods, photolithography spinner hoods, MAP or glovebox hoods, chemical lab hoods, and welding bench hoods.
- Secondary exhausted enclosures; Examples include non-routine access enclosures (gas cabinets), routine access enclosures (lab fume hoods), vacuum pump enclosures, chemical/flammable liquid dispensing cabinet, gas cabinets, and equipment cabinets.

Section 7.7 Slot hoods usually consist of a narrow exhaust opening and a plenum chamber. The function of the slot is solely to provide uniform air distribution. The high slot velocity generates high pressure losses and does not contribute toward capture velocity. Uniform exhaust air distribution across the slot is obtained by sizing slot width and plenum depth so that velocity through the slot is much higher than in the plenum. Because of this the pressure loss through the slot is high compared with the pressure loss through the plenum. A 2,000 ft/min (10 m/s) slot velocity and 1,000 ft/min (5 m/s) plenum velocity will usually provide uniform flow and moderate pressure drop.

Air distribution for rectangular and round capture hoods can be achieved by air flow within the hood rather than by pressure drop as for the slot hood. The plenum (length of hood from face to tapered hood to duct connection) should be as long as possible. The hood take-off should incorporate a 60-degree to 90-degree total included tapered angle. Multiple take-offs may be required for long hoods. End take-off configurations require large plenum sizes because all of the air should pass in one direction.

Section 7.9 Methods for calculating required air dilution volumes may be found in the *Industrial Ventilation Manual*.[6]

Section 7.12 As it relates to ASHRAE 110, the performance rating or performance factor is a series of numbers and letters consisting of the letters AM, AI, or AU and a two- or three-digit number, AM yyy, AI yyy, AU yyy, where AM identifies an “as manufactured” test, AU identifies an “as used” test, AI indentifies an “as installed” test, and yyy is the control level of tracer gas established by test. A test rating of AI 0.05, for example, would indicate that the hood, as installed, controls leakage into the laboratory to 0.5 ppm at the manikin’s sensing point with the tracer gas release rate of 4.0 lpm. Other standards of good practice may also include similar measures of performance. Another approach used in the past is to estimate the ratio of the concentration of a contaminate in the exhaust air vs. the concentration in the breathing zone of a person actually working in front of the hood. This has also been called the *Protection Factor (PF)*.

$$\text{Protection Factor (PF)} = \frac{C_{\text{exhaust air}}}{C_{\text{breathing zone}}}$$

Section 8.2 In addition to the acceleration of air, static pressure losses in LEV systems normally arise from the following causes:

(1) Entrance loss into hood;

(2) Friction of fluid flow in ducts, plenums and other airways, elbows, branch entries into mains;

(3) Turbulence and shock losses due to changes in air velocity or direction as in fittings such as elbows, branch entries, expansions or contractions in cross-sectional area;

(4) Resistance to flow of air-cleaning devices; and

(5) System effects at fan inlets and outlets.

Section 8.3 Balancing during design is the procedure of estimating/calculating the actual flow of air through each junction and duct run such that actual flowrates and static pressures at the fan can be predicted.

It should be noted that any duct/fan system will distribute airflow among its branches as soon as the fan is turned on and running smoothly, based on actual construction and static pressure usage in the system. Unfortunately, the system may not balance as the designer or User intended. With a *balanced design* method, the ventilation system is designed to operate at desired flows without further balancing after construction, i.e., it is balanced on paper during design. Careful construction mimics the design and the ventilation system operates with or without dampers, depending on the design procedure used.

LEV systems are normally designed or evaluated using the Velocity Pressure Method of design, as described in the references. The Velocity Pressure Method of design is a balanced design approach, which attempts to equate system losses to fractions of velocity pressure in the ductwork:

Loss = K • VP • d where K is the loss factor, VP is the average velocity pressure, and d is the air density correction factor.

Other balanced design procedures include: the Total Pressure Method, the Equivalent Foot method, the Plenum method, and the Damper Balance method. These methods are described in the ACGIH® *Industrial Ventilation Manual*[6] and in other references.

The balanced design with no dampers or with permanently fixed dampers will not perform well unless the supply air system is also designed as a fixed delivery system. In buildings with variable air volume comfort ventilation systems, a control link between tempered room supply air and LEV exhaust air volume flows is required to meet the intent of this standard. Under such conditions, one may specify commissioning standards that would include consideration of the range of exhaust flows acceptable for duct transport velocity, the range of flows acceptable for comfort ventilation in the supply system, and establish a suitable control mechanism. The supply flow should track the exhaust flow within a suitable range. For example, supply flow maintains 85 to 95% of exhaust flow, to insure negative static pressure in workrooms needing local exhaust ventilation. Untempered makeup air is generally discouraged because it increases the likelihood of condensation problems.

Section 9.1 International Fire Code Section 37 provides for treatment devices, which prevent an accidental release of air contaminants above 50% of the IDLH at the stack. The IFC also references 25% (versus 10%) of the LFL for ducting throughout. Check your local fire and building codes, if necessary.

Section 9.3 Refer to Code of Federal Regulations 40, Parts 60-64 for sampling methods for regulated emissions. The Emissions Measurement Technical Information Center at http:\\www.epa.gov\ttn\direct\html lists regulated and other test methods for emissions.

Section 10.2 Ensure that the fan inlet and outlet are located a sufficient distance from any elbow, obstruction or other air flow altering system component. If these components must be placed within six duct diameters of the fan inlet or outlet, the designer accounts for the associated pressure loss. Further discussion on fan systems effects can be found in the AMCA *Fan Applications Manual*(8) and the *Industrial Ventilation Manual*.(6)

Section 10.11. Shutoff capabilities can also be provided at the hood so that hood users can shut the system down during emergencies.

Section 12.1 Many of the activities of commissioning are similar to O&M practices, e.g., one must be able to access the equipment to measure pressures, read gages, and see the equipment during operation. Designing for commissioning achieves the same needs as designing for easy testing, troubleshooting, and servicing.

Commissioning has assumed the traditional role of quality assurance. Emission control problems can often be traced to a lack of QA during the design, construction, and O&M of the building and/or its ventilation systems.

ASHRAE Guideline 1–1989 Guidelines for the Commissioning of HVAC Systems, while not written for LEV systems, can provide useful guidance for developing an effective LEV system commissioning process.

The following statements apply to LEV systems:

- Commissioning is a QA process, which can be applied to local exhaust ventilation systems.
- Poor commissioning can result in inadequate exhaust performance.
- Users and building owners are becoming increasingly aware that commissioning is business as usual.

Commissioning normally consists of five phases:

Program ⇨ Design ⇨ Construction ⇨ Acceptance ⇨ Post-Acceptance

Program Phase. Owner requirements and budget established; team members identified; commissioning agent authorized; basis of design and planning documents prepared; all reviewed and approved by agent. A typical team consists of the User (or owner), the designer, the contractor, the installation contractor or installer, the O&M manager, an industrial hygienist or hygiene engineer, and a commissioning agent. Environmental evaluations for permitting begin at this phase.

Design Phase. Design completed and reviewed; specifications and contract documents prepared and reviewed; commissioning plan finalized. Engineering calculations and potential fan system effect should be reviewed during this phase.

Construction Phase. Exhaust systems built, tested, put into operation; commissioning plan modified as necessary.

Acceptance Phase. Mostly completed system turned over to owner; performance tests verifies total system operation and reliability; documentation completed and turned over to owner.

Post-Acceptance Phase. First year of operation; testing and observation of systems during different seasons and uses; all documents brought up to date.

The cost of commissioning has been shown to be 0.25–2 percent of construction costs. Retrofits to inadequately-built exhaust systems, in contrast, can be as high as 20% of initial construction costs. Users of the commissioning process are more likely to demonstrate compliance with ISO 9000 requirements for quality assurance.

Section 12.4 Good practices which will help assure effective operation over the expected lifetime of most LEV equipment include: (Note: More stringent practices may be required for heavy industrial systems.)

Gage of Ducts. Steel sheet metal ducts should be constructed of gages not less than those given in appropriate Sheet Metal and Air Conditioning Contractors National Association (SMACNA) publications. Heavier gages are required where there is danger of damage from exterior sources. Field welding on gages lighter than 16 is difficult and frequently impractical.

Reinforcing of Certain Parts. Hoods, booths, enclosures, elbows, and bends should be made from metal at least two gages heavier than required for ducts. For ducts No. 14 gage and heavier, the elbows, bends, and straight duct may be of the same gage. For large booths and enclosures where the use of heavier gage metal may involve an economic penalty, gages of the same weight as connecting duct work may be used provided the structure is adequately braced and flanged to prevent buckling or damage from normal abuse.

Duct Fabrication. Duct work should be so fabricated as to offer a minimum of resistance to air flow. The designer and sheet metal contractor should refer to the appropriate SMACNA publication for fabrication details.

Duct Interiors. Interiors of all ducts should be smooth and free from obstructions.

Girth Joints. Girth joints of sheet metal duct (except welded construction) should be made so that the outlet end of one length fits into the inlet end of the next length in the direction of air flow.

Welding of Ducts. Spot welding may be used in place of rivets in equal number provided steel-to-steel fusion at each weld is secured. Arc welding of black iron 18-gauge and lighter is not recommended for field fabrication.

Branch duct entries to the main duct. Branch ducts should not enter at any point along the outside half of the radius of a bend or elbow. Branch ducts entering mains should terminate at the wall of the main duct and not protrude into the main. The entering hole in the main duct should be cut the full size of the entering branch at the angle of entry, and the joint should be smooth inside.

Junctions with submains or mains should be made at an angle not greater than 45 degrees measured along the center lines of the two ducts; 30 degrees or less is recommended where feasible.

Branch Ducts and Transformations. Junctions should be made at the side or top of a transformation piece. Junctions should not be made into the bottom of the piece.

Elbow Construction. Ninety-degree elbows in round duct should be of smooth contour or at least five-piece construction for ducts 6 inches (152 mm) in diameter or less, and of seven-piece construction for larger ducts; or of equivalent smooth contour. A proportional number of pieces are required for elbows other than 90 degrees. The centerline radius should be 2x and no less than 1.5x the duct diameter unless lack of space prohibits the use of long bends. In this case, additional static pressure will be required for the system.

Transition Construction. Transition pieces should be tapered at an angle of about 15 degrees. Transition pieces should increase in cross-sectional area by the amount necessary to maintain the air velocity established and should be constructed of material equal in gage to the material of the connecting duct at the larger end.

Reduction of Friction Losses. Except for the purpose of balancing the system, branch duct connections to hoods, booths, and enclosures should be shaped to minimize the orifice and resistance losses due to the flow of air into the system.

Telescopic Joints. Telescopic joints should be constructed so that the inside duct connected to the hood should extend into the outside duct at least one duct diameter, but in no case less than 6 inches (152 mm). The end of the outside duct should have a reinforcing band or bead. The fixed member should be firmly supported.

Positive Action for Hood Devices. Telescopic joints and other adjustable devices for hoods should be air tight and rapid in action and should be so constructed that they will be easily adjustable.

Limitations of Flexible Ductwork. Where flexible ductwork is necessary, a non-collapsible metal type should normally be used, although flexible hose used in applications requiring higher flexibility than metal can provide, while also providing for adequate means of repair and replacement, may be of non-metal construction. The User should document the reasons for such usage. Only that portion which must be flexible should be constructed of the flexible material. A minimum length of flexible ductwork should be used so that the required bending radius is not less than the minimum bending radius as specified by the manufacturer. To perform static pressure calculations correctly, obtain the friction loss factor for the duct from the manufacturer.

Fan Location. Fans are normally located outdoors to reduce noise in the space and to reduce contaminant leakage from the positively pressurized outlet side of the exhaust fan. Smaller fans with construction and ductwork connections which assure continued airtight performance, and which meet noise requirements, may be located inside the building. The User should document the reasons for such usage. Locate the fan where it is easily accessible for maintenance personnel. Provide sufficient space so they can lay out tools, test the equipment and change belts, filters etc. without putting the worker in jeopardy. Mounting equipment in the rafters, on slanted roofs, and at the edge of unprotected roofs is discouraged, since the O&M personnel will have to comply with fall protection regulations.

Location of Clean-outs. Clean-out openings should be provided in horizontal runs of duct carrying dust-laden air, and especially near elbows, junctions, and vertical duct runs. The spacing of clean-out doors should not exceed 12 feet (3.66 m) for ducts of 12 inch (0.31 m) diameter or less, but may be greater for larger ducts. This recommendation does not usually apply to ducts carrying gases, non-condensable vapors, and non-settling aerosols.

Size of Clean-outs. Clean-out openings should be of a size that will permit ready access to the interior of the duct. Removable caps should be installed at all terminal ends, and the last branch connection should be not more than 6 inches (0.15 m) from the capped end. When ductwork is constructed with flanged joints for purposes of cleaning, inspection openings should be provided in such ductwork in place of regular clean-outs.

Drainage of Ducts. Where condensation of water vapor or other liquid may occur within the exhaust system, provision should be made for proper sloping and drainage. The drain pipe should be provided with either a water-leg seal or a valve. Clean-outs may also be needed in ductwork where vapors tend to condense and pocket.

LEV System Leakage. Particular care should be taken to guard against leakage from ducts carrying contaminated air under pressure, especially if the contaminant is hazardous. Such leakage is frequently best prevented by installing the air-cleaning equipment on the suction side of the exhaust fan.

Support of Vertical Runs. Vertical runs of branch ducts should be supported rigidly.

Support of Horizontal Runs. Horizontal runs of duct, including branch ducts extending more than 3 feet (0.91 m), should be securely supported and fastened to some substantial portion of the building structure or to other permanent supports. Such supports should be on centers not more than 12 feet (3.66 m) apart for 8 inch (0.20-m) and smaller ducts and on centers not more than 20 feet (6.1 m) apart for larger duct.

Reinforcing of Ducts. Duct reinforcing, if necessary, should be done on the outside of the duct.

Weather Protection and Guarding of Fan. Exhaust fan and motor should be mounted on a firm foundation and adequately protected from weather. Drives connecting fan and motors should be shielded with guards and adequately protected from weather. For ventilating equipment located in coastal areas LEV systems may need extra coating to protect the system from corrosion. For belt-driven fans, it is advisable to leave a small hole in the guard in line with the center of the driven shaft to facilitate checking the fan speed without removing the guard.

Fan Installation. Whenever possible, select fans that are AMCA rated for Air Performance and Sound. Provide a drain port at the bottom of the fan housing to drain rain water. Vibration isolators on ductwork attached to the fan inlet should be mounted on the outside of the duct.

Stackheads. An offset stackhead may be required if rain draining into the system is detrimental to the fan, the product or the air pollution control system.

Gauges & Sensors. As necessary, provide sensors before and after air cleaning equipment to indicate when servicing is required; provide a sensor indicating the flowrate into the fan; provide a sensor to monitor bonding systems; locate sensor gauges on an annunciator panel or in a location easily readable by the operator.

Future Expansion. If expansion is anticipated in the near future (~5 years) or if the designer may have under-estimated static pressure requirements, choose a fan class that is capable of running about 25% faster. Also install dampers in each run of the system to facilitate balancing as changes occur.

Section 12.10 Consider interlocking process machinery and LEV systems for conditions where LEV is needed to control air contaminants using sensors for all critical parameters, including air flowrates, duct transport velocities, electrical bonding, and so forth.

Section 13.9 Typical items that could be included in a maintenance schedule are:

(1) *Hoods*. Measure the volumetric flowrate exhausted through each hood periodically. This can be accomplished, for example, by taking static pressure measurements at an accessible point in each branch line (close to the hood throat but not within two duct diameters of the duct entry) when the system is originally installed and approved. The first pressure measurements become baseline readings. Subsequent readings then give the desired checks on performance. Alternately, a permanently installed alarmed pressure tap can be provided which will warn the user when flowrates have changed. A 20% change in static pressure is usually associated with a 10% change in flowrate.

(2) *Motor, fan, and drive*. Check bearings, belts, pulley sheaves, and the age of the equipment.

(3) *Fan rotation*. Check the direction of fan rotation after any maintenance on motor or wiring.

(4) *Employee exposures*. When airborne contaminants are generated and employee exposures are possible, monitor airborne contaminants periodically at each significant operation and compare the results with similar measurements made when the system was first installed and approved. Since the primary function of an exhaust ventilating system is to control air contamination, this is the only true index of ventilation effectiveness.

(5) *Air cleaning device*. Where air pollution, toxicity of effluent, or value of materials in the effluent require the need for it, take periodic air samples at the discharge of air-cleaning devices. Samples taken on both sides of such a device will provide a measure of its operating efficiency. Samples taken at the discharge show the overall effectiveness of the cleaning equipment.

(6) *LEV system*. Inspect the entire system at least once each year. Inspection includes checking all ductwork and other equipment for external damage, abrasion, and corrosion. Electroplating shops and processes using certain regulated materials such as lead and asbestos require more frequent inspections. Processes generating flammable and explosive aerosols may require more frequent inspections.

Sections 14.5 and 14.6 Hood performance test types include:

Qualitative tests. Smoke, visible vapor trails, soap bubbles, and neutral buoyancy balloons can be useful because they are visible. Smoke tubes and smoke generators (typically based on titanium tetrachloride smoke) are quick, easy, and inexpensive, the smoke is irritating, so move employees out of the smoke path. Particle generators (smoke) should not be used in cleanrooms.

Breathing Zone (BZ) analysis. Measure contaminant concentrations in the employee's breathing zone using traditional industrial hygiene testing methods. Exposures below some acceptable level (e.g., some percent of the TLV chosen by the user) are subjective evidence of satisfactory containment.

Semi-quantitative. A more rigorous approach is to establish containment performance parameters (CPP), compare them to acceptable standards, and assume containment if standards are met. For example, if CPP test results match the following accepted parameters, containment may be assumed. (This is the method most often used for field testing after hoods are in use.)

Containment performance parameters:

1. The hood static pressure measurement remains at the desired values.
2. No observed smoke or vapor is emitted from the hood or enclosure when tested with visible smoke or water vapor.
3. Hood capture and/or face velocities are measured and meet velocity criteria (e.g., average face velocity of 80–120 fpm for laboratory hoods and open wet station hoods, capture velocity of 350 fpm for grinding operations, and so forth; management determines acceptable face and capture velocities for each operation. See References.
4. No single measurement of face velocity exceeds some set value of the average face velocity (e.g., 20% at wet sink station hoods).
5. Turbulent air mixing velocities at the face of the hood do not exceed some set value (e.g., 40 fpm at lab hoods with the hood exhaust turned off).
6. Hood users understand and always follow correct work practices.
7. The hood is configured as the manufacturer intended it to be.
8. The operation has not changed from its original criteria (e.g., more toxic chemicals are not being used, additional equipment has not been added to the hood, and so forth.)

Quantitative tests. Tests similar to the ASHRAE 110–1995 tracer gas test have been adopted by some[2] as a required test method for approving laboratory hoods, semiconductor wet station hoods, and others.

In the ASHRAE 110 test, for example, a tracer gas (e.g., SF_6) is released at a known rate (e.g., 4 lpm) inside the hood from a single dispersion nozzle. Samples of tracer gas are obtained in the breathing zone (BZ) of a manikin standing at different positions in front of the hood. Results are reported as:

AU yyy or AI yyy or AM yyy.

The yyy refers to BZ concentration, typically 0.01 ppm to 0.1 ppm.
The AU, AI, and AM refer to as used, as installed (before usage begins), and as manufactured.

Protection Factor (PF). Another useful approach is to estimate the ratio of the concentration of a contaminate in the exhaust air vs. the concentration in the breathing zone of a person actually working in front of the hood:

$$\text{Protection Factor (PF)} = \frac{C_{\text{exhaust air}}}{C_{\text{breathing zone}}}$$

Appendix B. ANSI/AIHA® Z9.2 Audit Form

The attached form can be used to audit compliance with the Standard

Audit item numbers refer to Standard sections. As noted in Section 4.13, compliance with the Standard should only be claimed by the User when all applicable provisions or elements of the Standard are met.

4. General Requirements

- ❑ 4.1 Persons designing, operating, maintaining, and testing an LEV system are qualified by training or experience to perform their jobs.
- ❑ 4.2 Design and operation of LEV systems are based on the following minimum baseline data: emission source behavior, air behavior in the space, and worker interaction with emission sources.
- ❑ 4.3 LEV system designs and specifications are reviewed by industrial hygienists and other appropriate professionals before construction or installation begins.
- ❑ 4.4 LEV system design and specification conform to provisions of this Standard, or to other published standards of good practice if demonstrably equal to or more stringent than this Standard.
- ❑ 4.5 LEV systems are designed, installed, and accepted in accordance with a Commissioning Plan approved by the User.
- ❑ 4.6 Exhaust volume flowrates and equipment sizes are selected to dilute air contaminants to an acceptable concentration in the exhaust system.
- ❑ 4.7 Static pressure losses throughout the LEV system are estimated before fans are chosen and before construction or installation begins.
- ❑ 4.8 LEV systems are constructed throughout of structurally appropriate and chemically compatible materials.
- ❑ 4.9 LEV systems are provided with performance monitoring systems.
- ❑ 4.10 LEV systems are provided with equipment redundancy as necessary to assure continuous protection of employees.
- ❑ 4.11 The LEV system is kept clean and free of fire and smoke-producing materials, and maintained in good working order throughout its working lifetime.
- ❑ 4.13 Users of this standard do not claim compliance with this Standard unless every applicable element is complied with.

5. Plant Layout and Construction

- ❑ 5.1 LEV design considers plant layout and construction.
- ❑ 5.2 Buildings are suitably adapted for hazardous operations and meet local building and fire codes related to LEV systems.
- ❑ 5.3 Equipment surfaces are constructed to permit easy cleaning and draining.
- ❑ 5.4 Where tools, processes, or equipment generate different dusts, fumes, or vapors which could, if intermixed, result in a realistic health or explosion hazard, or corrosion, such contaminants are exhausted by separate exhaust ventilation systems.
- ❑ 5.5 LEV systems handling radioactive materials are shielded, isolated, labeled, or otherwise controlled such that they comply with design specifications and dose limits for personnel and the general public established by the appropriate regulatory authority.

6. Makeup Air Systems

- ❑ 6.1 Air exhausted through a local exhaust ventilation system is replaced by a makeup air system.
- ❑ 6.2 The designer or User determines the static pressure relationship required in the exhausted space (re: adjacent spaces) and provide makeup air volumes accordingly.
- ❑ 6.3 The designer or User optimizes the supply-to-exhaust-system airflow patterns in the space.
- ❑ 6.4 Recirculated air from a local exhaust ventilation system meets the requirements of ANSI/AIHA® Z9.7–1998.
- ❑ 6.5 Makeup air delivery does not reduce the performance of the local exhaust ventilation system.
- ❑ 6.6 The intake for the makeup air system is located so as to prevent the uptake of contaminants from exhaust systems, process vents, or other contaminant sources.
- ❑ 6.7 Makeup air is filtered at the air intake to protect ventilation system equipment.

- ❑ 6.8 Makeup air units are designed and operated to supply appropriate air volume flowrates at all times.
- ❑ 6.9 A monitoring system are provided which signals a malfunction of the makeup air system.
- ❑ 6.10. Makeup air is clean.
- ❑ 6.11 When makeup air is used to provide thermal comfort for workers, the system is designed and operated in accordance with ASHRAE and AIHA® standards.
- ❑ 6.12 Where makeup air is heated by a direct-fired heater, the factors listed in Section 6.12 of the Standard are met.
- ❑ 6.13 Makeup air is not used as push air in a push-pull LEV system.

7. Exhaust Hoods

- ❑ 7.1 Exhaust hoods are selected, designed, constructed, operated, and maintained to provide control of routine and anticipated chemical emissions.
- ❑ 7.2 Exhaust hood design, construction, and operation consider and document the factors listed in Section 7.2 of the Standard.
- ❑ 7.3 Exhaust air flowrate selection is determined by capture, containment, and airflow requirements.
- ❑ 7.4 Exhaust hoods are ?to the maximum extent feasible, selected, designed, constructed, installed, operated, and maintained to provide control of unplanned emissions or equipment failure emissions.
- ❑ 7.5 Exhaust hoods are equipped with airflow monitoring systems, procedures or devices.
- ❑ 7.6 Before routine use begins, exhaust hood performance is tested to assure that contaminant capture and containment performance meets the Users requirements.
- ❑ 7.7 Selection of hood type is determined by the needs for hood performance.
- ❑ 7.8 Hood design, placement, and operation ensures a uniform flow of air into the hood.
- ❑ 7.9 Enclosing hoods enclose the emission source to the maximum extent possible. Capture hoods are placed as close to the emission sources as possible.
- ❑ 7.10 Hoods and connecting equipment are designed and operated to avoid fires and explosions.
- ❑ 7.11 Hood design, operation, and testing consider and document the parameters listed in Section 7.11 of the Standard.
- ❑ 7.12 Manufacturers and suppliers of prebuilt hoods and exhausted tools/enclosures provide the information shown in Section 7.12 of the Standard.

8. Ductwork and Stacks

- ❑ 8.1 Duct design is performed by those properly trained and educated.
- ❑ 8.2 Static pressure losses are estimated throughout the duct system.
- ❑ 8.3 Duct systems are designed using a balanced-design approach.
- ❑ 8.4 Duct materials are chosen to be compatible with air contaminants exhausted.
- ❑ 8.5 Duct velocities are sufficient to prevent the settling of dry aerosols. Where mists, sticky particles, or condensing materials are carried in the duct, provision for duct cleaning is provided.
- ❑ 8.6 Round duct is used in local exhaust ventilation systems on the upstream side of the fan or air-mover.

- ❑ 8.7 When it is necessary to carry exhaust ducts through fire walls, automatic dampers are provided in the exhaust duct in accordance with local and NFPA codes.
- ❑ 8.8 Stacks are located and designed such that (1) re-entrainment of exhausted air is held to a minimum and (2) workers in the vicinity of the stack are not exposed to hazardous concentrations of exhausted contaminants.
- ❑ 8.9 Process exhaust stack outlets are well above adjacent air intakes if they are within re-entrainment distance.
- ❑ 8.10 Process exhaust stack outlet velocities are selected to protect against backdrafting.
- ❑ 8.11 Flexible vibration isolators are mounted at the fan inlet on the outside of exhaust ducts.

9. Air Cleaning Equipment

- ❑ 9.1 Local exhaust systems are designed, built, operated, and/or modified after obtaining the appropriate emissions and/or air pollution permits required by local authorities.

- ❑ 9.2 Cleaning equipment selection is determined by the air contaminant to be separated from the exhaust air.
- ❑ 9.3 The User establishes and operates testing and maintenance programs to assure reliable and consistent operation of the cleaning equipment.
- ❑ 9.4 Handling, transport, and disposal of effluents and collected materials from the air cleaning equipment meet RCRA, DOT, and local codes and does not create a hazard to employees handling the materials.

10. Fans and Air Moving Devices

- ❑ 10.1 The data shown in Standard Section 10.1 are developed and documented prior to the final selection of a fan or air mover:
- ❑ 10.2 Fan selection considers possible system effect losses.
- ❑ 10.3 Fans normally are chosen such that the System Operating Point (SOP) lies on a steep part of the forward part of the fan curve.
- ❑ 10.4 The User develops safe O&M procedures and installs appropriate guards to assure safe use, operation, and maintenance of fans.
- ❑ 10.5 Fan selection considers long-term air contaminant effects on the fan and fan wheel.
- ❑ 10.6 Fans serving dust-collecting and corrosive vapor local exhaust systems are located on the clean-air side of the air pollution control device.
- ❑ 10.7 Safe means are provided to allow the wheel of a fan to be examined without removing connecting duct work.
- ❑ 10.8 Where flammable vapors gases, or dusts are carried in the airstream, precautions are taken to protect against ignition by means of a spark in the fan or motor.
- ❑ 10.9 Where wire mesh screen is used on the fan discharge, the screen opening is no smaller than necessary to prevent entry of birds or rodents.
- ❑ 10.10 Following installation, and after maintenance of the fan, the correct direction of rotation of the fan wheel is ascertained.
- ❑ 10.11 Fan on/off switches are located within view of the fan and no further than 50 away.
- ❑ 10.12 Outlet ductwork from exhaust fans does not leak or is not routed through occupied spaces.

11. Management of LEV systems

- ❑ 11.1 The User develops written management policies that support successful performance of exhaust ventilation systems.
- ❑ 11.2 The User develops, promulgates, and enforces a work practices program.
- ❑ 11.3 The User develops a written LEV maintenance program.
- ❑ 11.4 The User establishes and maintains an LEV testing and monitoring program.

12. Commissioning

- ❑ 12.1 The User utilizes a commissioning approach to procurement, design, installation, construction, and acceptance of LEV systems.
- ❑ 12.2 Local exhaust ventilation systems are constructed so that they can be operated safely, economically, and maintained easily.
- ❑ 12.3 Materials of construction are compatible with the process and air contaminants to be exhausted.
- ❑ 12.4 Construction assures the continued effective operation of the LEV system over its expected lifetime.
- ❑ 12.5 System components are constructed to be as airtight as possible on the upstream side of the fan; system components are constructed to be airtight on the downstream side of the fan when such components are inside the building.
- ❑ 12.6 Ductwork is accessible for inspection and maintenance and is protected against external damage.
- ❑ 12.7 The use of dampers and blast gates is not permitted in the main or submain ducts of an exhaust system unless provided for the specific purpose of complete air shutoff, or for balancing airflow in the system. After adjustment, they are fixed in place to prevent unauthorized or accidental adjustments.
- ❑ 12.8 Where it is necessary to install motors, lights, switches, or fan controls in system atmospheres with potential fire or explosion hazards, approved equipment for the specific hazard are used.
- ❑ 12.9 No additional duct runs are added to an existing LEV system unless (1) such additions were specifically provided for in the original design or such additions are approved by a person qualified to perform system design, and (2) modifications to the existing LEV system can be made and not result in deteriorated performance of the existing LEV system.

❑ 12.10 Where failure of the exhaust equipment could result in airborne concentrations of contaminants at or above IDLH levels, the exhaust and supply air systems and the process machinery controls are interlocked so process machinery can operate only when the exhaust and supply systems are in operation.

13. Operations and Maintenance

❑ 13.1 The User establishes and maintains a program of safe operating procedures.

❑ 13.2 Equipment that is a part of an LEV system is operated in accordance with the manufacturer's instructions.

❑ 13.3 Employees working with LEV systems are instructed on the proper operating method and the reasons for the installation and operating procedures.

❑ 13.4 No process or equipment on which exhaust ventilation has been installed for employee protection or fire control are operated when the exhaust system is not functioning properly.

❑ 13.5 Every LEV system handling particulate matter is operated with inlets to the system open unless the system was specifically designed for safe operation with some inlets closed.

❑ 13.6 LEV systems are maintained in good working order.

❑ 13.7 Maintenance personnel responsible for LEV systems are instructed on its proper operation and the reason for the installation.

❑ 13.8 Maintenance personnel responsible for an LEV system are trained to "troubleshoot" the system in the event of malfunction.

❑ 13.9 The User establishes a program of preventive and scheduled maintenance.

❑ 13.10 Manufacturers' recommendations for the maintenance of LEV system components are included in the maintenance schedule.

❑ 13.11 The User establishes and supports a program to keep maintenance records.

❑ 13.12 Drawings, plans and specifications are kept up-to-date as LEV systems change.

❑ 13.13 The user establishes and complies with lock-out, tag-out programs for both the electrical power sources and mechanical energy sources.

14. Testing, Balancing, and Operational Checks

❑ 14.1 Performance standards and operating criteria, if not defined during design, are established by the User for every component of an LEV system.

❑ 14.2 The User selects test methods and test instruments which can measure the established performance criteria of Section 14.1.

❑ 14.3 After construction or modification, the LEV system is tested before routine service begins to assure that the system meets the established performance criteria of Section 14.1.

❑ 14.4 The LEV system is periodically tested and monitored in accordance with a schedule determined by the User.

❑ 14.5 The hood captures, receives, or contains air contaminants at some specified performance criteria established by the User.

❑ 14.6 Qualitative and/or quantitative tests are adopted by the User to assure hood capture and containment performance.

❑ 14.7 Each LEV system is balanced during the Commissioning process and thereafter on a schedule determined by the User.

❑ 14.8 Persons performing testing and balancing are qualified by training, experience, or certification to perform the work.

❑ 14.9 Testing and balancing instrumentation is suitable for the measurements to be taken.

❑ 14.10. Testing and balancing instruments are calibrated in accordance with manufacturers recommendations and on a schedule to be determined by the User.

❑ 14.11 Records of testing and balancing are maintained by the User.

❑ 14.12 Makeup or replacement air systems are also included in any LEV testing protocol.

❑ 14.13. Testing and monitoring equipment are safe for the intended use.

❑ 14.14 System testing results are made available to those with a need to know.

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American National Standard for

ANSI/AIHA® Z9.2–2012 Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems

BY THE ANSI/AIHA® Z9.2 SUBCOMMITTEE

This standard describes fundamental good practices related to the commissioning, design, selection, installation, operation, maintenance, and testing of local exhaust ventilation (LEV) systems used for the control of employee exposure to airborne contaminants.

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