

Laboratory Standards and Guidelines

This is a compilation of excerpts from many of the applicable laboratory standards and guidelines currently used within the industry. It provides owners, engineers, architects and laboratory users an overview of standards and guidelines that apply to the design and use of today's laboratory. Consult all relevant local, state and federal building codes to determine which standards and guidelines from this document apply to a particular facility.

Fume Hood Face Velocity

Federal Register—OSHA

Appendix A, section C.4.(g)

“Quality...air flow into and within the hood should not be excessively turbulent; hood face velocity should be adequate (typically 60-100 lfm).”

Prudent Practices

p. 178

“In most cases, the recommended face velocity is between 80 and 100 feet per minute (fpm). Face velocities between 100 and 120 fpm may be used for substances of very high toxicity or where outside influences adversely affect hood performance. However, energy costs to operate the fume hood are directly proportional to the face velocity. Face velocities approaching or exceeding 150 fpm should not be used, because they may cause turbulence around the periphery of the sash opening and actually reduce the capture efficiency of the fume hood.”

Industrial Ventilation— ACGIH

p. 10-40

“*Supply Air Distribution:* For typical operation of a laboratory hood, the worker stands at the face of the hood and manipulates the apparatus in the hood. The indraft at the hood face creates eddy currents around the worker's body that can drag contaminants in the hood along the worker's body and up to the breathing zone. The higher the face velocity, the greater the eddy currents. For this reason, higher face velocities do not result in greater protection as might be supposed.”

p. 10-40

“*Selection of Hood Face Velocity:* The interaction of supply air distribution and hood face velocity makes any blanket specification of hood face velocity inappropriate. Higher hood face velocities will be wasteful of energy and may provide no better or even poorer worker protection. The ANSI/ASHRAE Hood Performance Test may be used as a specification. The specified performance should be required of both the hood manufacturer and the designer of the room air supply system.”

p. 10-41, Table 10.35.1. Laboratory Hood Ventilation Rates

Condition	cfm/ft ² Open Hood Face
1. Ceiling panels properly located with average panel face velocity < 40 fpm. Horizontal sliding sash hoods. No equipment in hood closer than 12 inches to face of hood. Hoods located away from doors and trafficways.*	60
2. Same as 1 above; some traffic past hoods. No equipment in hoods closer than 6 inches to face of hood. Hoods located away from doors and trafficways.*	80
3. Ceiling panels properly located with average panel face velocity < 60 fpm or ceiling diffusers properly located; no diffuser immediately in front of hoods; quadrant facing hood blocked; terminal throw velocity < 60 fpm. No equipment in hood closer than 6 inches to face of hood. Hoods located away from doors or trafficways.*	80
4. Same as 3 above; some traffic past hood. No equipment in hood closer than 6 inches to face of hood.	100
5. Wall grilles are possible but not recommended for advance planning of new facilities.	

* Hoods near doors are acceptable if 1) there is a second safe egress from the room; 2) traffic past hood is low; and 3) door is normally closed.

NFPA 45

p. 45-13, section 8.4.6

“Chemical hood face velocities and exhaust volumes shall be sufficient to contain contaminants generated within the hood and exhaust them outside of the laboratory building.”

p. 45-13, section 8.4.7

“The hood shall provide containment of the possible hazards and protection for personnel at all times when chemicals are present in the hood.”

p. 45-30, section A.8.4.7

“Laboratory fume hood containment can be evaluated using the procedures contained in the ASHRAE 110, *Method of Testing Performance of Laboratory Fume Hoods*. Face velocities of 0.4 m/sec to 0.6 m/sec (80 ft/min to 120 ft/min) generally provide containment if the hood location requirements and laboratory ventilation criteria of this standard are met.

“In addition to maintaining proper fume hood face velocity, fume hoods that reduce the exhaust volume as the sash opening is reduced should maintain a minimum exhaust volume to ensure that contaminants are diluted and exhausted from a hood. The chemical fume hood exhaust airflow should not be reduced to less than 127 L/ sec/m² (25 ft³/min/ft²) of internal hood work surface even when the sash is fully closed except where a written hazard character-

ization indicates otherwise. This characterization should be performed in accordance with ASHRAE 110, *Method of Testing Performance of Laboratory Fume Hoods*.”

ANSI/AIHA Z9.5

pp. 16-18, section 3.3.1

Requirements:

“The average face velocity of the hood shall produce sufficient capture and containment of hazardous chemicals generated under as-used conditions.

“An adequate face velocity is necessary but is not the only criterion to achieve acceptable performance and shall not be used as the only performance indicator...”

“Room and operator dynamics have significant effects on hood performance at low face velocities. Therefore, it is important to understand the effects of dynamic challenges on hood performance so that standard operating procedures and user restrictions can be established. Operating a hood below 60 fpm (0.30 m/s) is not recommended since containment cannot be reliably quantified at low velocities and significant risk of exposure may be present.

“The mechanism that controls the exhaust fan speed or damper position to regulate the hood exhaust volume shall be designed to ensure a minimum exhaust volume in constant volume systems equal to the larger of 50 cfm/ft of hood width, or 25 cfm/ft² of hood work surface area, except where a written hazard characterization indicates otherwise, or if the hood is not in use.”

Clarification of above requirements:

“60–80 fpm (0.30–0.41 m/s): Hoods with excellent containment characteristics operating under relatively ideal environmental conditions (i.e., room design characteristics) and with prudent operating practices can provide adequate containment in this velocity range although at an increased level of risk. Containment must be verified quantitatively in this range and effective administrative controls should be in place and compliance must be enforced.

“80–100 fpm (0.41–0.50 m/s): Most hoods can be operated effectively with relatively low risk in this velocity range although containment should still be quantitatively verified. Proper operator training and enforcement of administrative controls are still highly recommended. This is the range recommended for a majority of laboratory chemical hoods.

“100–120 fpm (0.51–0.61 m/s): This velocity range has similar characteristics as 80–100 fpm (0.41–0.51 m/s) but at significantly higher operating costs. Containment may be slightly enhanced in this range and hoods that do not contain adequately in the 80-100 fpm (0.41–0.51 m/s) range may be improved by operating in this range.

“120–150 fpm (0.61–0.76 m/s): Although most hoods can operate effectively in this range, performance is not significantly better than at the lower ranges of 80–100 fpm (0.41–0.51 m/s) and 100–120 fpm (0.51–0.61 m/s) and the operating cost penalty imposed by high face velocities in this range is severe and is not recommended for this reason.

>150 fpm (>0.76 m/s): Most laboratory experts agree that velocities above 150 fpm (0.76 m/s) at the design sash position are excessive at operating sash height and may cause turbulent flow creating more potential for leakage.”

SEFA 1.2

p. 31, section 5.3.4

“Determine specified average face velocity for fume hood being tested. Perform the following test to determine if fume hood velocities conform to specifications.

“Face velocity shall be adequate to provide containment. Face velocity is not a measure of safety.

“Refer to ASHRAE 110-1995 (or latest edition) for velocity measurement procedures.

“Face Velocity Guide—The most widely accepted range of average face velocity is 60 FPM to 100 FPM. The measured deviation across the face may vary ± 20 FPM. (For more information on this topic, refer to Section 12.0 Regulatory and Industry Consensus standards.)”

Fume Hood Monitoring

Federal Register—OSHA

Appendix A, section C.4.(b)

“Hoods...each hood should have a continuous monitoring device to allow convenient confirmation of adequate hood performance before use.”

Prudent Practices

p. 180

“Make sure that a continuous monitoring device for adequate hood performance is present, and check it every time the hood is used.”

**Industrial Ventilation—
ACGIH**

p. 10-45

“13. Provide adequate maintenance for the hood exhaust system and the building supply system. Use static pressure gauges on the hood throat, across any filters in the exhaust system, or other appropriate indicators to ensure flow is appropriate.”

**NIH Design Policy and
Guidelines**

pp. F. 124 to F. 125, section F.16.2

“Fume hoods in new laboratory facilities shall have a pressure-independent flow-monitoring device connected to a local audiovisual alarm within the laboratory area. For existing facilities, the implementation of airflow devices for fume hoods occurs during the renovation phase. When the fume exhaust falls below a preset safety level, the alarm will sound and the alarm light will come on.”

Fume Hood Use

Federal Register—OSHA

Appendix A, section E.1.(n)

“Use of hood:...As a rule of thumb, use a hood or other local ventilation device when working with any appreciably volatile substance with a TLV of less than 50 ppm...”

“Leave the hood ‘on’ when it is not in active use if toxic substances are stored in it or if it is uncertain whether adequate general laboratory ventilation will be maintained when it is ‘off.’”

Prudent Practices

p. 179

“In addition to protecting the laboratory worker from toxic or unpleasant agents used in them, fume hoods can provide an effective containment device for accidental spills of chemicals. There should be at least one hood for every two workers in laboratories where most work involves hazardous chemicals, and the hoods should be large enough to provide each worker with at least 2.5 linear feet of working space at the face. If this amount of hood space is not available, other types of local ventilation should be provided, and special care should be exercised to monitor and restrict the use of hazardous substances.”

ANSI/AIHA Z9.5

p. 2, section 2.1.1 (requirements)

“Adequate laboratory fume hoods, special purpose hoods, or other engineering controls shall be used when there is a possibility of employee overexposure to air contaminants generated by a laboratory activity.”

Laboratory Air Recirculation

Federal Register—OSHA

Appendix A, section C.4.(a)

“4. Ventilation...ensure that laboratory air is continually replaced, preventing increase of air concentrations of toxic substances during the working day...”

Prudent Practices

p. 192

“All air from chemical laboratories should be exhausted outdoors and not recirculated. Thus, the air pressure in chemical laboratories should be negative with respect to the rest of the building unless the laboratory is also a clean room.”

ASHRAE Applications Handbook

p. 14.9

“Laboratories in which chemicals and compressed gases are used generally require nonrecirculating or 100% outside air supply systems. The selection of 100% outside air supply systems versus return air systems should be made as part of the hazard assessment process, which is discussed in the section on Hazard Assessment. A 100% outside air system must have a very wide range of heating and cooling capacity, which requires special design and control.”

“Supply air systems for laboratories include both constant-volume, high-low volume, and variable-volume systems that incorporate either single-duct reheat or dual-duct configurations, with distribution through low-, medium- or high-pressure ductwork.”

NFPA 45

p. 45-12, section 8.3.1

“Laboratory ventilation systems shall be designed to ensure that chemicals originating from the laboratory shall not be recirculated.”

p. 45-12, section 8.3.2

“The release of chemicals into the laboratory shall be controlled by enclosure(s) or captured to prevent any flammable and/or combustible concentrations of vapors from reaching any source of ignition.”

p. 45-13, section 8.4.1

“Air exhausted from chemical fume hoods and other special local exhaust systems shall not be recirculated.”

**Industrial Ventilation—
ACGIH**

p. 7-25

“*Industrial Exhaust Recirculation:* Where large amounts of air are exhausted from a room or building in order to remove particulate, gases, fumes or vapors, an equivalent amount of fresh tempered replacement air must be supplied to the room. If the amount of replacement air is large, the cost of energy to condition the air can be very high. Recirculation of the exhaust air after thorough cleaning is one method that can reduce the amount of energy consumed. Acceptance of such recirculating systems will depend on the degree of health hazard associated with the particular contaminant being exhausted as well as other safety, technical, and economic factors.”

ANSI/AIHA Z9.5

pp. 49-50, section 5.3.6.1 (requirements)

“Air exhausted from the general laboratory space (as distinguished from exhaust hoods) shall not be recirculated unless one of the following sets of criteria is met:

1) Criteria A

- There are no extremely dangerous or life-threatening materials used in the laboratory;
- The concentration of air contaminants generated by the maximum credible accident will be lower than short-term exposure limits...;
- The system serving the laboratory chemical hoods is provided with installed spares, emergency power, and other reliability features as necessary.

2) Criteria B

- Recirculated air is treated to reduce contaminant concentrations...;
- Recirculated air is monitored continuously for contaminant concentrations or provided with a secondary backup air-cleaning device that also serves as a monitor (via a HEPA filter in a series with a less efficient filter, for particulate contamination only)...
- Provision of 100% outside air, whenever continuous monitoring indicates an alarm condition.”

NIH Design Policy and Guidelines

p. D. 8, section D.4.3

“Laboratory HVAC systems shall utilize 100% outdoor air, conditioned by central station air-handling systems to offset exhaust air requirements. Laboratory supply air shall not be recirculated or reused for other ventilation needs.”

Laboratory/Building Pressurization

Federal Register—OSHA

Appendix A., section C.4.(a)

“Ventilation...direct air flow into the laboratory from non-laboratory areas and out to the exterior of the building.”

Prudent Practices

p. 192

“In all cases, air should flow from the offices, corridors, and support spaces into the laboratories. All air from chemical laboratories should be exhausted outdoors and not recirculated. Thus, the air pressure in chemical laboratories should be negative with respect to the rest of the building unless the laboratory is also a clean room.”

ASHRAE Applications Handbook

p. 14.12

“For the laboratory to act as a secondary confinement barrier, the air pressure in the laboratory must be maintained slightly negative with respect to adjoining areas. Exceptions are sterile facilities or clean spaces that may need to be maintained at a positive pressure with respect to adjoining spaces.”

NIH Design Policy and Guidelines

p. D. 9, section D.4.5

“Laboratory air shall flow from low-hazard to high-hazard use areas. In general, laboratories shall be maintained at 47 L/s per module negative relative to non-laboratory spaces. Administrative areas in laboratory buildings shall always be positive with respect to corridors and laboratories.”

NFPA 45

p. 45-13, section 8.3.4

“The air pressure in the laboratory work areas shall be negative with respect to corridors and nonlaboratory areas of the laboratory unit except in the following instances:

- “(1) Where operations such as those requiring clean rooms preclude a negative pressure relative to surrounding areas, alternate means shall be provided to prevent escape of the atmosphere in the laboratory work area or unit to the surrounding spaces.
- “(2) The desired static pressure level with respect to corridors and nonlaboratory areas shall be permitted to undergo momentary variations as the ventilation system components respond to door openings, changes in chemical hood sash positions, and other activities that can for a short term affect the static pressure level and its negative relationship.
- “(3) Laboratory work areas located within a designated hazardous electrically classified area with a positive air pressure system as described in NFPA 496, *Standard for Purged and Pressurized Enclosed Electrical Equipment*, Chapter 7, Pressurized Control Rooms.”

ANSI/AIHA Z9.5

pp. 27-28, section 5.1.1

Requirements:

“As a general rule, airflow shall be from areas of low hazard, unless the laboratory is used as a Clean Room (such as Class 10 000 or better), or an isolation or sterile laboratory, or other special-type laboratories. When flow from one area to another is critical to emission and exposure control, airflow monitoring devices shall be installed to signal or alarm that there is a malfunction.

“Air shall be allowed to flow from laboratory spaces to adjoining spaces only if

- There are no extremely dangerous and life-threatening materials used in the laboratory;
- The concentrations of air contaminants generated by the maximum credible accident will be lower than the exposure limits required by 2.1.1.”

Clarification of above requirements:

“What really is desired is an offset air volume...Attempts to design using direct pressure differential measurement and control vs. controlling the offset volume may result in either short or extended periods of the loss of pressure when the doors are open or excessive pressure differentials when the doors are closed, sufficient to affect the performance of low pressure fans...

“When the differential pressure design basis is used, the relative volumes of supply and exhaust air to each room should be set so that air flows through any opening, including open doorways, at a minimum velocity of 50 fpm (0.25 m/s) and a preferred velocity of 100 fpm (0.51 m/s) in the desired direction.”

p. 30, section 5.1.1.1 (requirements)

“Airlocks shall be utilized to prevent undesirable airflow from one area to another in high hazardous applications, or to minimize volume of supply air required by Section 5.1.1.

“An airlock shall consist of a vestibule or small enclosed area that is immediately adjacent to the laboratory room and having a door at each end for passage. Airlocks shall be applied in such a way that one door provides access into or out of the laboratory room, and the other door of the airlock provides passage to or

from a corridor (or other mandatory area). Airlock doors shall be arranged with interlocking controls so that one door must be fully closed before the other door may be opened.”

p. 30, section 5.1.1.2 (requirements)

“If the direction of airflow between adjacent spaces is deemed critical, provision shall be made to locally indicate and annunciate inadequate airflow and improper airflow direction.”

Laboratory Airflow Exchange Rates

Federal Register—OSHA

Appendix A., section C.4.(f)

“Performance. Rate: 4-12 room air changes/hour is normally adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control.”

Prudent Practices

p. 192

“A general ventilation system that gives 6 to 12 room air changes per hour is normally adequate. More airflow may be required to cool laboratories with high internal heat loads, such as those with analytical equipment, or to service laboratories with large specific exhaust system requirements.”

ASHRAE Applications Handbook

p. 14.8

“The total airflow rate for a laboratory is dictated by one of the following:

1. Total amount of exhaust from containment and exhaust devices
2. Cooling required to offset internal heat gains
3. Minimum ventilation rate requirements...

“Minimum airflow rates are generally in the range of 6 to 10 air changes per hour when the space is occupied; however, some spaces (e.g., animal holding areas) may have minimum airflow rates established by specific standards or by internal facility policies...The maximum airflow rate for the laboratory should be reviewed to ensure that appropriate supply air delivery methods are chosen such that supply airflows do not impede the performance of the exhaust devices.”

Industrial Ventilation—ACGIH

p. 7-21

“‘Air changes per hour’ or ‘air changes per minute’ is a poor basis for ventilation criteria. The required ventilation depends on the generation rate and toxicity of the contaminant, not on the size of the room in which it occurs.”

NFPA 45

p. 45-29, section A.8.2.2

“A minimum ventilation rate for unoccupied laboratories (e.g., nights and weekends) is four room air changes per hour. Occupied laboratories typically operate at rates of greater than eight room air changes per hour, consistent with the conditions of use for the laboratory.”

NIH Design Policy and Guidelines

p. D. 9, section D.4.7

“The ventilation rate for laboratory HVAC systems is driven by three factors: fume hood demand, cooling loads, and removal of fumes and odors from the general laboratory work area. The minimum air-change rate for laboratory space is six air changes per hour regardless of space cooling load.”

Manifolded Exhaust Systems

ASHRAE Applications Handbook

p. 14.10

“Each fume hood may have its own exhaust fan, or fume hoods may be manifolded and connected to one or more common central exhaust fans...

“These can be classified as pressure-dependent or pressure-independent. **Pressure-dependent systems** are constant volume only and incorporate manually adjusted balancing dampers for each exhaust device. If an additional fume hood is added to a pressure-dependent exhaust system, the entire system must be rebalanced, and the speed of the exhaust fans may need to be adjusted. Because pressure-independent systems are more flexible, pressure-dependent systems are not common in current designs.

“A **pressure-independent system** can be constant volume, variable volume, or a mix of the two. It incorporates pressure-independent volume regulators with each device. The system offers two advantages: (1) the flexibility to add exhaust devices without having to rebalance the entire system and (2) variable volume control...

“Running many exhaust devices into the manifold of a common exhaust system offers the following benefits:

- Lower ductwork cost
- Fewer pieces of equipment to operate and maintain
- Fewer roof penetrations and exhaust stacks
- Opportunity for energy recovery
- Centralized locations for exhaust discharge
- Ability to take advantage of exhaust system diversity
- Ability to provide a redundant exhaust system by adding one spare fan per manifold”

ANSI/AIHA Z9.5

p. 38, section 5.3.2.1 (clarification of requirements)

“Two or more exhaust systems may be combined into a single manifold and stack, if the conditions of 5.3.2.2 are met.”

pp. 40-41, section 5.3.2.2 (requirements)

“Laboratory chemical hood ducts may be combined into a common manifold with the following exceptions and limitations:

“Each control branch shall have a flow-regulating device to buffer the fluctuations in pressure inherent in manifolds.

“Perchloric acid hoods shall not be manifolded with nonperchloric acid hoods unless a scrubber is installed between the hood and the manifold.

“Where there is a potential contamination from hood operations as determined from the Hazard Evaluation and Analysis of Section 2.4, radioisotope hoods shall not be manifolded with nonradioisotope hoods unless in-line HEPA filtration and/or another necessary air-clearing system is provided between the hood and the manifold.

“Carbon bed filters shall be added for gases.”

pp. 41-42, section 5.3.2.4 (requirements)

“Unless all individual exhausts connected to the centralized exhaust system can be completely stopped without creating a hazardous situation, provision shall be made for continuous maintenance of adequate negative static pressure (suction) in all parts of the system.

As an alternative, if the hood is completely turned off, the hood shall be emptied and decontaminated and provisions shall be implemented to prevent the hood from backdrafting.

The VAV hood shall be provided with an emergency switch that allows the hood exhaust volume to return to the maximum.”

NFPA 45

p. 45-14, section 8.5.10

“8.5.10.1 Exhaust ducts from each laboratory unit shall be separately ducted to a point outside the building, to a mechanical room, or to a shaft...”

“8.5.10.2 Connection to a common laboratory hood exhaust duct system shall be permitted to occur within a building only in any of the following locations:

- (1) Mechanical room protected in accordance with...
- (2) Shaft protected in accordance with the chapter for protection of vertical openings of NFPA 101, *Life Safety Code*
- (3) A point outside of the building

“8.5.10.3 Exhaust ducts from chemical fume hoods and other exhaust systems shall be permitted to be combined within that laboratory unit...”

“8.6 Duct Velocities. Duct velocities of laboratory exhaust systems shall be high enough to minimize the deposition of liquids or condensable solids in the exhaust systems during normal operations in the laboratory hood.”

IMC Supplement

The original draft of the International Mechanical Code (IMC) stated that exhaust systems carrying hazardous substances must be independent of the other exhaust systems in a facility but an exception was later made for laboratories in IMC 510.4. Laboratories are defined as a place where chemicals are used in a non-production capacity, such as research, education, testing, analysis, or developmental activities (IMC 510.1, p. IMC-6). For the spaces that meet those criteria, IMC 510.4 does not apply to when all of the following conditions exist:

- All hazardous exhaust ductwork and lab exhaust in the occupied space and shafts operate under negative pressure.
- The hazardous exhaust ductwork manifolded with the occupied space originates in the same fire area.
- A flow regulating device is on each control branch.
- Perchloric acid hoods and their exhaust systems cannot be manifolded.
- Radioisotope hoods have filtration and/or carbon beds, when required.
- Biological safety cabinets have filters.
- Negative static pressure in the ductwork is maintained continuously (pp. IMC-6 to IMC-7).

In addition, IMC 510.7 requires ducts carrying hazard substances to be protected with an approved fire suppression system, but again, there are exceptions for laboratories:

This system must be installed in accordance with the International Building Code. Fire suppression systems are *not* required in these situations:

- When ducts convey nonflammable, noncombustible substances.
- When the largest cross-sectional duct diameter is less than 10 inches (254 mm).
- In laboratory hoods and exhaust systems (p. IMC-7).

Exhaust Stack Height

NFPA 45

p. 45-13, section 8.4.11

“Air exhausted from chemical fume hoods and special exhaust systems shall be discharged above the roof at a location, height, and velocity sufficient to prevent re-entry of chemicals and to prevent exposures to personnel.”

p. 45-30, section A.8.4.12

“Exhaust stacks should extend at least 3 m (10 ft) above the highest point on the roof to protect personnel on the roof. Exhaust stacks might need to be much higher to dissipate effluent effectively, and studies might be necessary to determine adequate design.”

ASHRAE Applications Handbook

p. 14.13

“Chapter 15 of the 1997 *ASHRAE Handbook—Fundamentals* describes a geometric method to determine the stack discharge height high enough above the turbulent zone around the building that little or no effluent gas impinges on air intakes of the emitting building. The technique is conservative and generally requires tall stacks that may be visually unacceptable or fail to meet building code or zoning requirements. Also, the technique does not ensure acceptable concentrations of effluents at air intakes (e.g., if there are large releases of hazardous materials or elevated intake locations on nearby buildings)...

“To increase the effective height of the exhaust stacks, both the volumetric flow and the discharge velocity can be increased to increase the discharge momentum (Momentum Flow = Density x Volumetric Flow x Velocity). The momentum of the large vertical flow in the emergent jet lifts the plume a substantial distance above the stack top, thereby reducing the physical height of the stack and making it easier to screen from view. This technique is particularly suitable when (1) many small exhaust streams can be clustered together or manifolded prior to the exhaust fan to provide the large volumetric flow and (2) outside air can be added through automatically controlled dampers to provide constant exhaust velocity under variable load. The drawbacks to the second arrangement are the amount of energy consumed to achieve the constant high velocity and the added complexity of the controls to maintain the constant flow rates. Dilution equations presented in Chapter 16 of the 2005 *ASHRAE Handbook—Fundamentals* or mathematical plume analysis (e.g., Halitsky 1989) can be used to predict the performance of this arrangement, or performance can be validated through wind tunnel testing. Current mathematical procedures tend to have a high degree of uncertainty, and the results should be judged accordingly.”

ANSI/AIHA Z9.5

pp. 47-48, section 5.3.5 (requirements)

“Exhaust discharge from stacks shall be in accordance with the *ASHRAE 1999 Handbook—HVAC Applications*, Chapter 43.

“In any event the discharge shall be a minimum of 10 ft (3 m) above adjacent roof lines and air intakes and in a vertical up direction.”

p. 38, section 5.3.2.1 (clarification of requirements)

“Two or more exhaust systems may be combined into a single manifold and stack...”

Exhaust Duct Velocity

**Industrial Ventilation—
ACGIH**

p. 3-18, Table 3-2. (partial) Range of Minimum Duct Design Velocities

Nature of Contaminant	Examples	Design Velocity
Vapors, gases, smoke	All vapors, gases and smoke	Any desired velocity (economic optimum velocity usually 1000-2000 fpm)
Fumes	Welding	2000-2500
Very fine light dust	Cotton lint, wood flour, litho powder	2500-3000
Dry dusts & powders	Fine rubber dust, Bakelite molding powder dust, jute lint, cotton dust, shavings (light), soap dust, leather shavings	3000-4000

NFPA 45

p. 45-14, section 8.6

“**Duct Velocities.** Duct velocities of laboratory exhaust systems shall be high enough to minimize the deposition of liquids or condensable solids in the exhaust systems during normal operations in the chemical fume hood.”

ANSI/AIHA Z9.5

p. 48, section 5.3.5 (requirements)

“A minimum discharge velocity of 3000 fpm (15.2 m/s) is required unless it can be demonstrated that a specific design meets the dilution criteria necessary to reduce the concentration of hazardous materials in the exhaust to safe levels...at all potential receptors.”

General Air Distribution Guidelines

ASHRAE Applications Handbook

p. 14.5

“Caplan and Knutson (1977, 1978) conducted tests to determine the interactions between room air motion and fume hood capture velocities with respect to the spillage of contaminants into the room. Their tests indicated that the effect of room air currents is significant and of the same order of magnitude as the effect of the hood face velocity. Consequently, improper design and/or installation of the replacement supply air lowers the performance of the fume hood.

“Disturbance velocities at the face of the hood should be no more than one-half and preferably one-fifth the face velocity of the hood. This is an especially critical factor in designs that use low face velocities. For example, a fume hood with a face velocity of 100 fpm could tolerate a maximum disturbance velocity of 50 fpm. If the design face velocity were 60 fpm, the maximum disturbance velocity would be 30 fpm.

“To the extent possible, the fume hood should be located so that traffic flow past the hood is minimal. Also, the fume hood should be placed to avoid any air currents generated from the opening of windows and doors. To ensure the optimum placement of the fume hoods, the HVAC system designer must take an active role early in the design process.”

NFPA 45

p. 45-13, section 8.3.5

“The location of air supply diffusion devices shall be chosen so as to avoid air currents that would adversely affect the performance of chemical fume hoods, exhaust systems, and fire detection or extinguishing systems.”

p. 45-29, section A.8.3.3

“Room air current velocities in the vicinity of fume hoods should be as low as possible, ideally less than 30 percent of the face velocity of the fume hood. Air supply diffusion devices should be as far away from fume hoods as possible and have low exit velocities.”

Prudent Practices

p. 178

“Tracer gas containment testing of fume hoods has revealed that air currents impinging on the face of a hood at a velocity exceeding 30 to 50% of the hood face velocity will reduce the containment efficiency of the hood by causing turbulence and interfering with the laminar flow of the air entering the hood. Thirty to fifty percent of a hood face velocity of 100 fpm, for example, is 30 to 50 fpm, which represents a *very* low velocity that can be produced in many ways. The rate of 20 fpm is considered to be still air because that is the velocity at which most people first begin to sense air movement.”

ANSI/AIHA Z9.5

p. 34, section 5.2.2 (requirements)

“Supply air distribution shall be designed to keep air jet velocities less than half, preferably less than one-third, of the capture velocity or face velocity of the laboratory chemical hoods at their face opening.”

p. 20, section 3.3.4 (requirements)

“Laboratory chemical hoods shall be located so their performance is not adversely affected by cross drafts. Windows in laboratories with hoods shall be fully closed while hoods are in use (emergency conditions excepted).”

Controls—Pressure-independent

ASHRAE Applications Handbook

p. 14.10

“Airflow monitoring and pressure-independent control may be required even with constant volume systems...Because pressure-independent systems are more flexible, pressure-dependent systems are not common in current designs...(Pressure-independent) volume regulators can incorporate either direct measurement of the exhaust airflow rate or positioning of a calibrated pressure-independent air valve.”

NIH Design Policy and Guidelines

p. F. 68, section F.11.17

“Exhaust air from laboratory equipment such as fume hoods and biosafety cabinets directed to a general central laboratory exhaust main is preferably controlled through pressure-independent terminal units.”

AIA

p. 33

“Chemical fume hood systems may be constant-volume or variable-volume types depending on user and facility management considerations of function, first cost, and life cycle cost issues. The exhaust of the hood should be provided with a pressure-independent flow-monitoring device connected to a local audiovisual alarm within the laboratory.”

Controls—General

ASHRAE Applications Handbook

p. 14.12

“Laboratory controls must regulate temperature and humidity, control and monitor laboratory safety devices that protect personnel, and control and monitor secondary safety barriers used to protect the environment outside the laboratory from laboratory operations...Reliability, redundancy, accuracy, and monitoring are important factors in controlling the lab environment. Many laboratories require the precise control of temperature, humidity, and airflows. Components of the control system must provide the necessary accuracy and corrosion resistance if they are exposed to corrosive environments. Laboratory controls should provide fail-safe operation, which should be defined jointly

with the safety officer. A fault tree can be developed to evaluate the impact of the failure of a control system component and to ensure that safe conditions are maintained.”

p. 14.12

“A true CAV (Constant Air Volume) system requires volume controls on the supply and exhaust systems.”

p. 14.19

“Energy can be used more efficiently in laboratories by reducing exhaust air requirements. One way to achieve this is to use variable-volume control of exhaust air through the fume hoods to reduce exhaust airflow when the fume hood sash is not fully open. Any airflow control must be integrated with the laboratory control system, described in the section on Control, and must not jeopardize the safety and function of the laboratory.

“Another energy-efficiency method uses night setback controls when the laboratory is unoccupied to reduce exhaust volume to one-quarter to one-half the minimum required when the laboratory is occupied. Timing devices, sensors, manual override, or a combination of these can be used to set back the controls at night. If this strategy is a possibility, the safety and function of the laboratory must be considered, and appropriate safety officers should be consulted.

“Also, fume sash configurations that limit the opening to less than the full open condition should be considered.”

ANSI/AIHA Z9.5

p. 15, section 3.2.6

Requirements:

“The supply and exhaust systems shall be balanced. If the laboratory uses variable air volume, the supply and exhaust shall modulate together to maintain this balance. In addition, modification of the hood exhaust shall not compromise the total laboratory exhaust. Any modification of the hood exhaust shall not compromise other fundamental concerns.”

Clarification of above requirements:

“It is recommended that VAV systems be equipped with emergency overrides that permit full design flow even when the sash is closed.”

NFPA 45

p. 45-13, section 8.5.8

“Controls and dampers, where required for balancing or control of the exhaust system, shall be of a type that, in event of failure, will fail open to ensure continuous draft.”

p. 45-15, section 8.10.6

“Chemical fume hoods equipped with control systems that vary the hood exhaust airflow as the sash opening varies and/or in conjunction with whether the laboratory room is in use (occupied/unoccupied) shall be equipped with a user accessible means to attain maximum exhaust hood airflow regardless of sash position when necessary or desirable to ensure containment and removal of a potential hazard within the hood.”

p. 45-15, section 8.10.3

“The design and installation of ducts from laboratory hoods shall be in accordance with NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids*, except that specific requirements in NFPA 45 shall take precedence.”

p. 45-15, section 8.10.4

“Automatic fire dampers shall not be used in laboratory hood exhaust systems.”

p. 45-15, section 8.10.5

“Fire detection and alarm systems shall not be interlocked to automatically shut down laboratory hood exhaust fans.”

p. 45-15, section 8.10.1

“Automatic fire protection systems shall not be required in laboratory hoods or exhaust systems except in the following cases:

- “(1) Existing hoods having interiors with a flame spread index greater than 25 in which flammable liquids are handled.
- “(2) If a hazard assessment shows that an automatic extinguishing system is required for the chemical fume hood, then the applicable automatic fire protection system standard shall be followed.”

p. 45-14, section 8.7.5

“Motors and their controls shall be located outside the location where flammable or combustible vapors or combustible dusts are generated or conveyed, unless specifically approved for that location and use.”

p. 45-11, section 5.6.1

“Electrical receptacles, switches, and controls shall be located so as not to be subject to liquid spills.”

AIA

p. 69

“Fire dampers shall not be provided on any fume hood system.”

Testing and Monitoring

Prudent Practices

p. 180

“All fume hoods should be tested, before they leave the manufacturer, by using ASHRAE/ANSI standard 110, *Methods of Testing Performance of Laboratory Fume Hoods*. The hood should pass the low- and high-volume smoke challenges with no leakage or flow reversals and have a control level of 0.05 parts per million (ppm) or less on the tracer gas test. ASHRAE/ANSI 110 testing of fume hoods after installation in their final location by trained personnel is highly recommended.”

ANSI/AIHA Z9.5

p. 64, section 6.6 (requirements)

“If practical, the exhaust flowrate from hoods shall be tested by measuring the flow in the duct by the hood throat suction method or by flow meter.

“If flow measurement in the duct is not practical, velocity at the hood face or opening shall be measured at a sufficient number of points to obtain a realistic average velocity, and multiplied by the open area in the plane of the velocity measurements to obtain the flowrate.

“If the flowrate is more than 10% different from design, corrective action shall be taken.”

p. 30, section 5.1.1.2 (requirements)

“If the direction of airflow between adjacent spaces is deemed critical, provision shall be made to locally indicate and annunciate inadequate airflow and improper airflow direction.”

p. 59, section 6.4

Requirements:

“Routine performance tests shall be conducted at least annually or whenever a significant change has been made to the operational characteristics of the hood system.

“A hood that is found to be operating with an average face velocity more than 10% below the designated average face velocity shall be labeled as out of service or restricted use and corrective actions shall be taken to increase flow.

“Each hood shall be posted with a notice giving the date of the routine performance test, and the measured average face velocity. If it is taken out of service it shall be posted with a restricted use or out-of-service notice. The restricted use notice shall state the requisite precautions concerning the type of materials permitted or prohibited for use in the hood.”

Clarification of above requirements:

“ANSI/ASHRAE 110-1995 may be used in the laboratory as an accepted test with specific values for the control levels (and the release rate if you depart from the standard). It also may be used for routine periodic testing, but it is somewhat expensive and other less rigorous tests may be adequate if conditions have not changed since commissioning tests.

“In addition to the hood tests, periodic testing at a minimum of 1-year intervals should ensure that:

- All other room exhaust provisions are within specifications;
- Room differential pressure is within specifications (if applicable);
- Room differential airflow is within specifications (if applicable).

“Periodic tests concerning face velocity or hood exhaust volume are valid indications of hood operation provided no changes have been made in that hood structure, supply air distribution, or other factors listed above that affect hood performance.

“The hood sash should not be lowered below design position to increase face velocity during routine tests. A decrease in face velocity at the design opening may be indicative of a problem with operation of the exhaust system.”

ASHRAE Applications Handbook

p. 14.5

“**Fume Hood Performance Criteria.** ASHRAE *Standard* 110, Method of Testing Performance of Laboratory Fume Hoods, describes a quantitative method of determining the containment performance of a fume hood. The method requires the use of a tracer gas and instruments to measure the amount of tracer gas that enters the breathing zone of a mannequin; this simulates the containment capability of the fume hood as a researcher conducts operations in the hood. The following tests are commonly used to judge the performance of the fume hood: (1) face velocity test, (2) flow visualization test, (3) large-volume flow visualization, (4) tracer gas test, and (5) sash movement test. These tests should be performed under the following conditions:

- Usual amount of research equipment in the hood; the room air balance set
- Doors and windows in their normal positions
- Fume hood sash set in varying positions to simulate both static and dynamic performance

“All fume hoods should be tested annually and their performance certified.”

NFPA 45

p. 45-16, sections 8.13.1 to 8.13.3

“When installed or modified and at least annually thereafter, chemical fume hoods, chemical fume hood exhaust systems, and laboratory special exhaust systems shall be inspected and tested. The following inspections and tests, as applicable, shall be made:

- (1) Visual inspection of the physical condition of the hood interior, sash, and ductwork...
- (2) Measuring device for hood airflow
- (3) Low airflow and loss-of-airflow alarms at each alarm location
- (4) Face velocity
- (5) Verification of inward airflow over the entire hood face
- (6) Changes in work area conditions that might affect hood performance

“Deficiencies in hood performance shall be corrected or one of the following shall apply:

- (1) The activity within the hood shall be restricted to the capability of the hood.
- (2) The hood shall not be used.

“Laboratory hood face velocity profile or hood exhaust air quantity shall be checked after any adjustment to the ventilation system balance.

p. 45-16, section 8.13.4 (Detectors and Alarms)

“8.13.4.1 Air system flow detectors, if installed, shall be inspected and tested annually.

“8.13.4.2 Where potentially corrosive or obstructive conditions exist, the inspection and test frequency shall be increased.”

p. 45-16, section 8.13.5 (Fans and Motors)

“8.13.5.1 Air supply and exhaust fans, motors, and components shall be inspected at least annually.

“8.13.5.2 Where airflow detectors are not provided or airflow-rate tests are not made, fan belts shall be inspected quarterly. Frayed or broken belts shall be replaced promptly; double sheaves and belts shall be permitted to be inspected semiannually.

p. 45-16, section 8.13.6

“Fixed fire extinguishing systems protecting filters shall be inspected quarterly for accumulation of deposits on nozzles and cleaned as necessary.”

Work Practices

ANSI/AIHA Z9.5

pp. 64-65, section 7 (requirements)

“...Many work practices might affect the overall safety and health in a laboratory.

“The following list concerns only those work practices that relate directly to hood performance and applies only when hazardous materials are to be used in the hood.

- The user shall not lean into the hood so that his/her head is inside the plane of the hood, as defined by the sash, without adequate respiratory and personal protection.
- Equipment and materials shall not be placed in the hood so that they block the slots or otherwise interfere with the smooth flow of air into the hood.
- All work shall be conducted at least 6 in. (15.2 cm) behind the plane of the sash (hood face).
- The horizontal sash or panels shall not be removed.
- The hood shall not be operated without the back baffles in place.
- Flammable liquids shall not be stored permanently in the hood or the cabinet under the hood unless that cabinet meets the requirements of NFPA 30-2000 and NFPA 45-2000 for flammable liquid storage.
- The sash or panels shall be closed to the maximum position possible while still allowing comfortable working conditions.
- Hood users shall be trained to close the sash or panels when the hood is not in use.
- The hood user shall not operate with the sashes opened beyond the design opening.
- Pedestrian traffic shall be restricted near operating hoods.

- Rapid movement within the hood shall be discouraged.
- The hood shall not be operated unless verified it is working.
- Rapid movement of the sash or panels shall be discouraged.”

p. 66, section 7.5 (requirements)

“Each hood shall be posted with a notice giving the date of the last periodic field test. If the hood failed the performance test, it shall be taken out of service until repaired, or posted with a restricted use notice.

“The notice shall state the partially closed sash position necessary for safe/normal operation and any other precaution concerning the type of work and materials permitted or prohibited.”

Prudent Practices

p. 179

“Many factors can compromise the efficiency of a hood operation. Most of these are avoidable; thus, it is important to be aware of all behavior that can, in some way, modify the hood and its capabilities. The following should always be considered when using a hood:

- Keep fume hood exhaust fans on at all times.
- If possible, position the fume hood sash so that work is performed by extending the arms under or around the sash, placing the head in front of the sash, and keeping the glass between the worker and the chemical source. The worker views the procedure through the glass, which will act as a primary barrier if a spill, splash, or explosion should occur.
- Avoid opening and closing the fume hood sash rapidly, and avoid swift arm and body movements in front of or inside the hood. These actions may increase turbulence and reduce the effectiveness of fume hood containment.
- Place chemical sources and apparatus at least 6 inches behind the face of the hood. In some laboratories, a colored stripe is painted on, or tape applied to, the hood work surface 6 inches back from the face to serve as a reminder. Quantitative fume hood containment tests reveal that the concentration of contaminant in the breathing zone can be 300 times higher from a source located at the front of the hood face than from a source placed at least 6 inches back. This concentration declines further as the source is moved farther toward the back of the hood.
- Place equipment as far to the back of the hood as practical without blocking the bottom baffle.
- Separate and elevate each instrument by using blocks or racks so that air can flow easily around all apparatus.
- Do not use large pieces of equipment in a hood, because they tend to cause dead spaces in the airflow and reduce the efficiency of the hood.
- If a large piece of equipment emits fumes or heat outside a fume hood, then have a special-purpose hood designed and installed to ventilate that particular device. This method of ventilation is much more efficient than placing the equipment in a fume hood, and it will consume much less air.
- Do not modify fume hoods in any way that adversely affects the hood performance. This includes adding, removing, or changing any of the fume hood components, such as baffles, sashes, airfoils, liners and exhaust connections.”

Selection of Specialty Hoods

Prudent Practices

pp. 184-185

“Auxiliary Air Hoods

“Quantitative tracer gas testing of many auxiliary air fume hoods has revealed that, even when adjusted properly and with the supply air properly conditioned, significantly higher worker exposure to the materials used in the hood may occur than with conventional (non-auxiliary air) hoods. Auxiliary air hoods should not be purchased for new installations, and existing auxiliary air hoods should be replaced or modified to eliminate the supply air feature of the hood. This feature causes a disturbance of the velocity profile and leakage of fumes from the hood into the worker’s breathing zone.

“The auxiliary air fume hood was developed in the 1970s primarily to reduce laboratory energy consumption. It is a combination of a bypass fume hood and a supply air diffuser located at the top of the sash. These hoods were intended to introduce unconditioned or tempered air, as much as 70% of the air exhausted from the hood, directly to the front of the hood. Ideally, this unconditioned air bypasses the laboratory and significantly reduces air conditioning and heating costs in the laboratory. In practice, however, many problems are caused by introducing unconditioned or slightly conditioned air above the sash, all of which may produce a loss of containment.”

p. 187

“Radioisotope Hoods

“Hoods used for work with radioactive sources or materials should be designed so that they can be decontaminated completely on a regular basis. A usual feature is a one-piece, stainless steel, welded liner with smooth, coved corners, which can be cleaned easily and completely. The superstructure of radioisotope hoods is usually made stronger than that of a conventional hood in order to support lead bricks and other shielding that may be required in the hood. Special treatment of the exhaust from radioisotope hoods may be required by government agencies to prevent the release of radioactive material into the environment. This usually involves the use of high-efficiency particulate air (HEPA) filters.”

ASHRAE Applications Handbook

p. 14.4

“**Auxiliary Air** (approximately constant volume airflow with approximately constant face velocity). A plenum above the face receives air from a secondary air supply that provides partially conditioned or unconditioned outside air.

“Application: Research laboratories—frequent or continuous use. Moderate to highly hazardous processes; varying procedures.

“Note: Many organizations restrict the use of this type of hood...

“Radioisotope. Standard hood with special integral work surface, linings impermeable to radioactive materials, and structure strong enough to support lead shielding bricks. The interior must be constructed to prevent radioactive material buildup and allow complete cleaning. The ductwork should have flanged neoprene gasketed joints with quick disconnect fasteners that can be readily dismantled for decontamination. High-efficiency particulate air (HEPA) and/or charcoal filters may be needed in the exhaust dust.

“Application: Process and research laboratories using radioactive isotopes.

“Perchloric Acid. Standard hood with special integral work surfaces, coved corners, and nonorganic lining materials. Perchloric acid is an extremely active oxidizing agent. Its vapors can form unstable deposits in the ductwork that present a potential explosion hazard. To alleviate this hazard, the exhaust system must be equipped with an internal water washdown and drainage system, and the ductwork must be constructed of smooth, impervious, cleanable materials that are resistant to acid attack. The internal washdown system must completely flush the ductwork, exhaust fan, discharge stack, and fume hood inner surfaces. The ductwork should be kept as short as possible with minimum elbows. Perchloric acid exhaust systems with longer duct runs may need a zoned washdown system to avoid water flow rates in excess of the capacity to drain the water from the hood. Because perchloric acid is an extremely active oxidizing agent, organic materials should not be used in the exhaust system in places such as joints and gaskets. Ducts should be constructed of a stainless steel material, with a chromium and nickel content not less than that of 316 stainless steel, or of a suitable nonmetallic material. Joints should be welded and ground smooth. A perchloric acid exhaust system should only be used for work involving perchloric acid.

“Application: Process and research laboratories using perchloric acid. Mandatory use because of explosion hazard.”

ANSI/AIHA Z9.5

p. 12, section 3.2.3 (clarification of requirements)

“Auxiliary supplied air hoods are not recommended unless special energy conditions or design circumstances exist.”

p. 14, section 3.2.4 (requirements)

“Perchloric acid hoods are laboratory hoods that meet the requirements in Sections 3.2.1 and 3.3 and NFPA 45.

- In addition: All inside hood surfaces shall use materials that will be stable and not react with perchloric acid to form corrosive, flammable, and/or explosive compounds or byproducts;
- All interior hood, duct, fan, and stack surfaces shall be equipped with water wash-down capabilities;
- All ductwork shall be constructed of materials that will be stable to and not react with perchloric acid and/or its byproducts and will have smooth welded seams;
- No part of the system shall be manifolded or joined to nonperchloric acid exhaust systems;
- No organic materials, including gaskets, shall be used in the hood construction unless they are known not to react with perchloric acid and/or its byproducts;

- Perchloric acid hoods shall be prominently labeled “Perchloric Acid Hood.”

NFPA 45

p. 45-15, section 8.11.1

“Perchloric acid heated above ambient temperatures shall only be used in a chemical fume hood specifically designed for its use and identified as follows:

FOR PERCHLORIC ACID OPERATIONS

“Exception: Hoods not specifically designed for use with perchloric acid shall be permitted to be used where the vapors are trapped and scrubbed before they are released into the hood.”

Sound Levels in Rooms

ASHRAE Applications Handbook

pp. 47.33-47.34

“Table 42 lists design guidelines for HVAC-related background sound appropriate to various types of space occupancies. Perceived loudness and task interference are factored into the numerical part of the RC rating. The sound-quality design target is assumed to be a neutral-sounding (N) spectrum, although some spectrum imbalance is probably tolerable within limits.”

Table 42. (partial) Design Guidelines for HVAC-Related Background Sound in Rooms

Room Types	RC(N); QAI ≤5 dB ^{a,b}
Office Buildings	
Executive and private offices	25 to 35
Conference rooms	25 to 35
Teleconference rooms	≤25
Open-plan offices	≤40
With sound masking	≤35
Corridors and lobbies	40 to 45
Hospitals and Clinics	
Private rooms	25 to 35
Wards	30 to 40
Operating rooms	25 to 35
Corridors and public areas	30 to 40
Laboratories (with fume hoods)	
Testing/research, minimal speech communication	45 to 55
Research, extensive telephone use, speech communication	40 to 50
Group teaching	35 to 45

^aValues and ranges are based on judgement and experience, not on quantitative evaluations of human reactions. They represent general limits of acceptability for typical building occupancies. Higher or lower values may be appropriate and should be based on a careful analysis of economics, space use, and user needs.

^bWhen sound quality in the space is important, specify criteria in terms of RC(N). If sound quality in the space is of secondary concern, the criteria may be specified in terms of NC or NCB levels of similar magnitude.

AIA

p. 37

“The typical maximum noise coefficient (NC) levels generated by HVAC systems in a laboratory is approximately NC 50 with hoods in an operating position and in the midpoint of the room. For laboratory hoods, noise levels should not exceed NC 60 at the face of the hood unless permitted by the facility safety personnel.”

References

American Conference of Governmental Industrial Hygienists (ACGIH). *Industrial Ventilation: A Manual of Recommended Practice, 25th Edition*. Cincinnati, OH: ACGIH, 2004.

American Institute of Architects (AIA), Center for Advanced Technology Facilities Design. *Guidelines for Planning and Design of Biomedical Research Laboratory Facilities*. Washington, DC: AIA, 1999.

American Industrial Hygiene Association (AIHA). *American National Standard for Laboratory Ventilation (ANSI/AIHA Z9.5-2003)*. Fairfax, VA: AIHA, 2003.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). *ASHRAE Handbook: 2007 HVAC Applications*. Atlanta, GA: ASHRAE, 2007.

International Code Council (ICC). *International Mechanical Code Supplement, 2007*. Country Club Hills, IL: ICC, 2007. Available online at <http://www.iccsafe.org/cs/codes/2007-08cycle/2007Supplement/IMC075.pdf>.

National Research Council, Committee on Prudent Practices for Handling, Storage, and Disposal of Chemicals in Laboratories. *Prudent Practices in the Laboratory: Handling and Disposal of Chemicals*. Washington, DC: National Academies Press, 1995. Available online at <http://books.nap.edu/html/prudent/>.

National Institutes of Health (NIH). *NIH Design Policy and Guidelines, 2003*. Available online at <http://orf.od.nih.gov/PoliciesAndGuidelines/DesignPolicy/policy-index.htm>.

National Fire Protection Association (NFPA). *NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals*. Quincy, MA: NFPA, 2004.

Occupational Safety and Health Administration (OSHA). *29 CFR Part 1910.1450, Appendix A, 2006*. Available online at http://www.osha.gov/pls/oshaweb/owadispl.show_document?p_table=STANDARDS&p_id=10107.

Scientific Equipment & Furniture Association (SEFA). *Laboratory Fume Hoods: Recommended Practices (SEFA 1.2-2006)*. Garden City, NY: SEFA, 2006. Available online at http://www.sefalabs.com/files/public/SEFA1_FumeHoods.pdf.