

Designing laboratory ventilation systems

Proper ventilation in labs is required to promote and maintain safety and protection to life and property.

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Learning objectives

- Understand the codes and standards that guide laboratory ventilation design.
- Learn how to design laboratory ventilation systems to meet system requirements.
- Understand key equipment functions.

Proper ventilation of laboratory settings is required to promote and maintain laboratory safety and protection to life and property. Items such as fume containment, worker safety, proper cleanliness through pressure relationships, filtration, air changes per hour (ACH), point of fume capture, temperature, and relative humidity requirements are elements necessary to design the ventilation system depending on the laboratory type. Codes identify ventilation measures to provide minimum requirements for the protection of life and property through prevention and control of fumes and containment of hazardous fumes and contaminants for worker safety.

There are four general types of laboratories noted in the ASHRAE Handbook—HVAC Applications:

1. Biological: Contains biologically active materials and includes areas such as biochemistry, cell biology, immunology, pharmacology, microbiology, and related fields. Clinical laboratories fall into this category.

2. Chemical laboratories that support both organic and inorganic synthesis and analytical functions.

3. Animal labs that include areas for the observation, manipulation, and pharmaco-

logical observation of laboratory animals and also include animal holding rooms.

4. Physical laboratories are spaces associated with physics and include lasers, optics, high- and low-temperature materials, and analytical instruments.

Biological laboratories commonly have chemical fume hoods and Class I and Class II bio-safety cabinets. Chemical labs generally have a number of fume hoods.

This article will provide information on hood types and ventilation criteria primarily on the first three types of labs, with discussion on contaminant containment, airflow practices, comfort conditioning, and the codes that govern the lab ventilation systems.

Applicable codes and standards

The 2011 edition of NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals applies to laboratory buildings, units, and work areas in which defined chemicals are handled or stored. Chapter 8, Laboratory Ventilating System and Hood Requirements, defines criteria and considerations for exhaust air and supply air systems including requirements for fume hood exhaust.

ANSI/AIHA Z9.5-2012 - Laboratory Ventilation describes required and recommended practices for the design and operation of lab ventilation systems for control of exposure to airborne contaminants. It does not apply to animal facilities, laminar

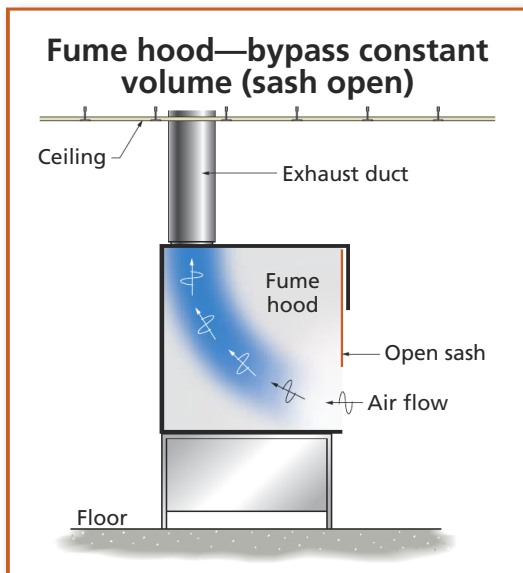


Figure 1: Standard constant volume fume hood shows a typical airflow pattern. All graphics courtesy: Smith Seckman Reid

Fume hood—bypass constant volume (sash closed)

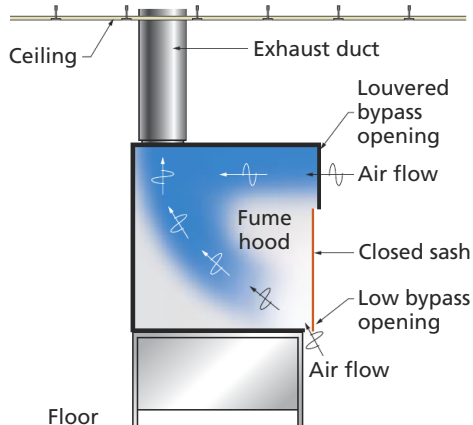


Figure 2: A bypass constant volume fume hood shows a typical airflow pattern with sash closed.

flow hoods, or bio-safety cabinets. Chapter 5 of this standard discusses laboratory ventilation system designs.

In the 2011 ASHRAE Handbook—HVAC Applications, Chapter 16 provides detailed descriptions of laboratory airflow, fume hood types, hazard assessments, exhaust systems, and applications to various lab types.

NFPA 99: Health Care Facilities Code, 2012 edition, has deleted the previously included chapter pertaining to laboratories and has added a new Chapter 4, which establishes four “Categories of Risk.” Also included is Chapter 9 outlining HVAC requirements for health care facilities. References are made in this chapter to NFPA 45 and ASHRAE Standards 90.1, 90A, and 170. This code will pertain primarily to clinical labs and related spaces whether within a hospital or separate building.

The 2010 edition of FGI Guidelines for Design and Construction of Health-care Facilities incorporates ASHRAE 170-2008 (with addenda): Ventilation of Health Care Facilities, which has specific requirements for laboratory ventilation including pressure relationships, air change rates, and temperature and relative humidity requirements.

ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality identifies

minimum ventilation rates in the breathing zone (Table 6-1) and minimum exhaust rates (Table 6-4) for laboratories and other spaces. (Standard 62.1-2013 was released in November 2013.)

The International Building Code (IBC) in the occupancy chapter 304 defines testing and research laboratories as a Business Group “B” occupancy. The International Mechanical Code (IMC) in Table 403.3 identifies minimum ventilation rates for science laboratories, and section 510 explains the requirements for laboratory exhaust systems.

There are other standards as well, such as OSHA 29 CFR 1910.1450: Occupational exposure to hazardous chemicals in laboratories and 21 CFR 58: Good Laboratory Practice Regulations, which while giving guidance, do not specifically require or specify ventilation rates or practices.

The more recent editions of several codes and standards have less focus on minimum or required air change rates and more focus on proper capture of fumes and contaminants, protection of workers, proper hood design and sash face velocity, supply air distribution, and pressure relationships. As with any project design, it is appropriate to determine which codes and standards are officially adopted by the authority having jurisdiction (AHJ) so that the correct and more stringent requirements can be incorporated into the design.

Fume hood types

Some common types of fume hoods used in clinical and chemical labs include standard fume hoods (constant volume exhaust airflow with variable face velocity) shown in Figure 1; bypass fume hood (constant

volume exhaust airflow) shown in Figure 2; variable volume fume hood (constant face velocity); and auxiliary air fume hood (constant volume exhaust airflow with 50% to 70% makeup air directly to hood).

Additionally, there are biological safety cabinets used in clinical lab settings that include Class I, which is similar to a chemical fume hood (see Figure 3); and a Class II A1 bio-safety cabinet that includes high-efficiency particulate absorption (HEPA) supply filters and HEPA exhaust filters that allow air to be re-circulated to the lab or exhausted directly outside (see Figure 4).

A Class II B1 bio-safety cabinet is similar; however, all air is removed through a HEPA filter and exhausted directly outside. A Class III bio-safety cabinet is completely enclosed and the work is done through gloves attached to the cabinet. This cabinet is exhausted directly outside with no recirculation allowed. The figures illustrate the differing airflow patterns and filtration requirements.

Generally, when working in a required clean environment such as when mixing medications (pharmacy) or working with infectious bacteria (research), airflow direction and air cleanliness are requirements.

Bio-safety cabinet, Class I

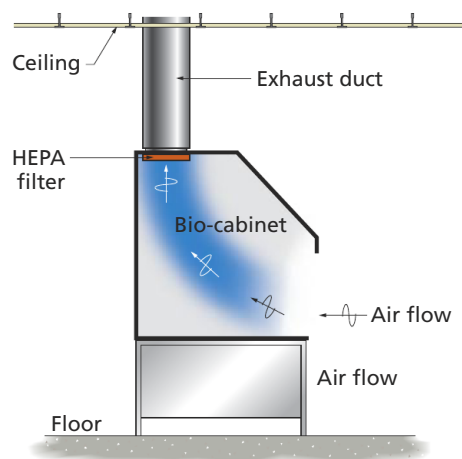


Figure 3: This Class I bio-safety cabinet shows a typical airflow pattern and HEPA filter location and laminar airflow.

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Bio-safety cabinets provide that cleanliness and direction with placement of the HEPA filters at the point of air delivery and removal. HEPA filters carry a minimum efficiency reporting value—commonly known as MERV—rating of 17 or higher.

Canopy hoods are open on the sides and primarily used to remove heat and water vapor from work areas. This hood type is not a true fume hood and should not be used as a substitute for one.

Open sash face velocities are between

75 ft per minute (fpm) and 120 fpm, with 100 fpm being an average velocity or rule of thumb for preliminary air calculations depending on what chemicals are stored or used in the hood. A velometer is attached to the fume hood to measure face velocity and inform users if the hood is safe to use. The hood sensors may alarm locally or be connected to the building automation system (BAS).

ASHRAE Standard 110: Method of Testing Performance of Laboratory Fume Hoods, defines the criteria for containment performance of a fume hood using a tracer gas and instruments to measure the amounts of tracer gas that enters the breathing zone of a mannequin. This test simulates the containment capability of the hood. A face velocity test, flow visualization test, large volume visualization test, tracer gas test, and sash movement test are all performed under this standard. The standard has specific requirements that must be met for the hood to comply.

Lab considerations

Clinical (biological) labs are generally located in hospitals but are sometimes separate, independent, and located away from the patient care and treatment areas. The lab may be classified as a business (B) occupancy, but if located within the hospital, it is subject to hospital licensing requirements, which include proper

air change rates, pressure relationships, and temperature and relative humidity requirements.

Functions associated with clinical labs include bacteriology, biochemistry, cytology, glass washing, histology, microbiology, pathology, and serology, as well as general lab functions. Many of these functions occur in smaller separate rooms due to odors, space temperature, and local capture requirements—as well as worker safety.

Supply airflow arrangement, airflow velocity, and point of capture are all extremely important to the overall function and successful containment of contaminants, odors, and gas vapors. Supply air devices of Group A (outlets mounted in or near the ceiling that discharge air horizontally) or E (outlets mounted in or near the ceiling that project primary air vertically) should be located in the ceiling where practical and deliver air so the velocity near a fume hood is approximately 50% of the hood face velocity or in most cases about 50 fpm. Hoods should be located out of the general walkway to minimize air currents and disruption of airflow. The HVAC design engineer must be involved in the lab planning to provide input to make the airflow and ventilation system functional without sacrificing safety. Computational fluid dynamics (CFD) may be a consideration in special cases or for complex HVAC/lab designs.

According to ASHRAE 62.1-2010, air (return, transfer, exhaust) shall be classified and its recirculation limited in accordance with its classification. There are four classes of air according to the standard.

Class 1: Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor. Class 1 air may be recirculated or transferred to any space.

Class 2: Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odors. Class 2 air may be recirculated within the space of origin, but not to a Class 1 space.

Class 3: Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.

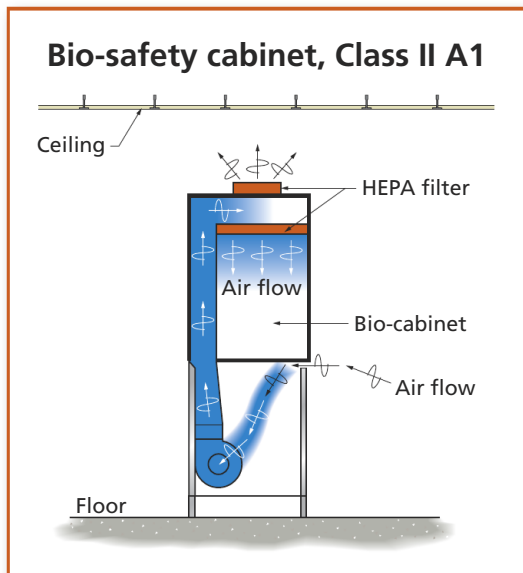


Figure 4: Class II A1 bio-safety cabinet has a typical airflow pattern and HEPA filter location with laminar airflow with clean supply and discharge air.

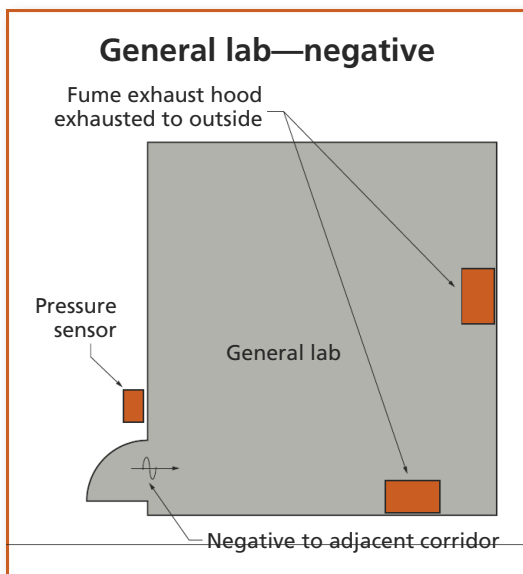


Figure 5: This general lab layout shows pressure relationship, typical fume hoods, and pressure sensor location. Airflow should be balanced to create a constant airflow offset resulting in the negative pressure relationship.

Class 3 air may be recirculated within the space of origin, but not to any other space.

Class 4: Air with highly objectionable fumes or gases or with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Class 4 air shall not be recirculated or transferred to any space nor recirculated within the space of origin.

Fume hood exhaust air is defined by Standard 62.1 in Table 5-2 as a Class 4. NFPA 45, paragraphs 8.3 and 8.4, also coincide with this requirement. Outdoor air established as a minimum ventilation rate in the Standard lists 10 cfm/person and 0.18 cfm/sq ft as a minimum for the breathing zone, which is defined as a space 3 to 72 in. above the floor.

Class 4 fume hood air discharge separation from air intakes or operable windows should be no closer than 30 ft but also meet the requirements of NFPA 45 and ANSI/AIHA Z9.5. Exhaust rates noted in ASHRAE 62.1 Table 6-4 for science labs note a minimum exhaust rate of 1.00 cfm/sq ft. With enough fume hoods this can usually be met, but localized exhaust for odor control and/or to meet minimum ventilation rates, air change, or non-recirculation requirements may also be needed.

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One thing to note is that ventilation air is defined in ASHRAE 62.1-2010 as that portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining indoor air quality (IAQ). While the majority of ventilation air used for proper IAQ and makeup air is outdoor air, it may be possible to filter and treat Class 2 and 3 exhaust air for use as makeup air or route the exhaust air through an energy recovery device with limited leakage, possibly saving energy.

Fume hood exhaust fans should be the type that discharge air vertically with suf-



Figure 6: This shows a bypass fume hood recessed into the lab wall on top of a flammable storage cabinet with workspace adjacent. Notice the airflow velocity meter on the right of the hood.

ficient velocity (3000 fpm minimum) and with adequate stack height (7 ft minimum above roof level, 10 ft recommended) to allow fan observation and maintenance without being exposed to the discharge airstream. The stack height provides better opportunity for dilution as well. To achieve sufficient air velocity, an exit cone that reduces the outlet stack diameter and thus increases the air velocity may be necessary. Keep in mind this sudden diameter

change can add a significant pressure drop by an average of 0.5 in. w.g. Redundant fans for critical applications are often employed to provide constant airflow in hoods and similar applications. Controls for fan operation usually consist of current sensing relays on fan motors, airflow switches, or differential pressure switches that prove fan operation and airflow. Control sequences of operation would identify lead/lag fan operation, alarm status, and proven airflow indication in a BAS and/or locally at the fume hood.

each hood to its own fan or be manifolded from several hoods to one fan. This latter arrangement requires careful air balancing and possibly redundant discharge fans to avoid an entire lab being shut down upon a loss of airflow. Additionally, compatibility of chemicals and contaminants must be carefully evaluated before exhaust streams are combined to avoid potential hazards or corrosion. Manifolded systems can be either constant volume or variable volume. Pressure-dependent systems are constant volume only and usually employ manual volume dampers for balancing. Any changes to a system such as adding or removing a fume hood would require re-balancing of the entire system.

Pressure-independent systems are either constant or variable volume and employ pressure-independent air volume regulators or air valves with each fume hood or exhaust device. Control of the airflow device can be from sash position sensors or air velocity sensors at the fume hood (face velocity determination). There are other methods as well, but the goal is to provide constant minimum required hood face velocity for proper fume and vapor capture.

Large chemical labs such as teaching and science laboratories with many fume hoods may be able to take advantage of differing usage factors that can reduce

Exhaust systems from chemical fume hoods may be ducted individually from

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Figure 7: These lab work counters have two bypass fume hoods at the back wall. Notice the surface-mounted light fixtures indicating tight above-ceiling space.

the amount of exhaust and makeup air required, thus saving energy and increasing equipment life. The usage factor must be used prudently and generally takes the following into consideration: total number of fume hoods, available airflow diversity, type of fume hood controls, laboratory makeup air and ventilation system type, number of devices (hoods) that must operate continuously, and hours per session/day hoods are actually in use.

Some chemicals such as formalin, formaldehyde, and glutaraldehyde are used as tissue preservatives and sterilants in clinical labs and similar health care settings. Many times these chemicals are used in operations performed in the open at counter level with the transfer of the liquid from one container to another by pouring or by gravity through a hose. This action allows fumes to become airborne and must be captured near the point of use by proper airflow direction. Airflow across the back of the worker with the point of capture and pickup at the counter level is a good method. Air velocity at the work surface needs to be slow enough to not evaporate the chemical, but yet adequate enough at the inlet (100 fpm minimum) to collect the vapors and prevent them from permeating the adjacent work stations. Best practice guides and standards for the safe use of

these chemicals prepared by OSHA and the Association for the Advancement of Medical Instrumentation (AAMI) recommend air change rates and point of vapor release airflow guidelines.

Air balance and pressurization of lab spaces can be tricky with controls and air system responses continually fluctuating due to opening of doors to adjacent spaces or airflow volumes changing to accommodate space temperature requirements. Accurate air measurements of supply air devices and exhaust systems are needed to balance the system. Strategic placement of pressure sensors will help determine if the required pressure relationship is being maintained. ANSI Z9.5 recommends that an air volume rate offset be used rather than controlling to a specific differential pressure. However, this offset will typically result in a 0.01 to 0.02 in. w.g. differential. Figure 5 shows a general lab with pressure sensor locations.

Duct construction should be specified and provided to achieve less than 1% leakage of design airflow; however, the design goal for both supply air (positive) and exhaust air (negative) duct systems should be for zero leakage. Exhaust duct construction and materials should be appropriate for the chemicals and fumes that are to be captured. The HVAC design-

ers should consult with lab users and safety personnel to obtain a list of the types and quantities of chemicals proposed to be used both in and outside of fume hoods, along with storage quantities anticipated. The chemical type will help the designer choose the correct duct material and jointing method to effect safe movement of the vapors and contaminants.

Space temperature (70 to 75 F) and relative humidity requirements are dependent on the lab function and heat gain to the space. Lab personnel wearing protective clothing may require temperatures in the lower portion of the range in order to remain comfortable. While a specific relative humidity is not identified in the various codes, it is usually maintained in the 30% to 60% range. With the constant volume air supply in most labs, temperature control of occupied work areas is usually achieved through single duct reheat systems or double duct air terminal units.

The MERV ratings are a measurement scale established by ASHRAE 52.2-2007 that identifies the efficiency and capture capability of particle sizes from 10 microns to less than 0.3 microns. The MERV ratings range from 1 through 20 with the higher the value, the greater the capture and efficiency. A MERV 8 filter will trap greater than 90% of particles sizes 3.0 to 10 microns. A MERV 13 filter has a dust spot efficiency of 89% to 90% and will capture droplet nuclei of 1.0 to 3.0 microns such as that from a sneeze. Higher MERV ratings of 16 will capture bacteria and particles as small as 0.30 microns. Usually, a MERV 14 (90% to 95% efficiency) is used in an air system supplying air to a lab.

Air supplied to labs requires filtration of a MERV 13 minimum in central air systems requiring either 1 or 2 filter beds in order to provide relatively clean air for the lab environment. Some functions, such as pharmacological preparation, infectious, or radioactive material use, require HEPA filters on both the supply and exhaust airstreams. Sometimes the HEPA filters are installed at the point of air delivery into the room, but more often the work is

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isolated to a Class I or Class II bio-safety cabinet with the HEPA filters installed in the cabinet. Filters in the exhaust stream of these cabinets must be designed to allow the safe removal, disposal, and replacement of these filters, such as with a bag-in/bag-out type of filter holding assembly. Work in a bio-safety cabinet requires a clean work surface but also allows for the dispersion of bacteria and related particles. Proper capture of these particles through filtration is essential for safe operation. A bag-in/bag-out housing incorporates a bag that completely covers the filter prior to its removal so all particles are kept on the filter and not accidentally released into the occupied environment or onto personnel changing the filter.

Animal facility considerations

Laboratory animals require comfortable, clean, and temperature-controlled conditions that afford proper safety and welfare of each animal species. The

HVAC design for such spaces must consider the temperature and relative humidity ranges associated with not only the animals, but the research protocol for the particular study. Air distribution and air movement are dependent on the housing of the animals. Open cages, shoebox cages, species type, number and size of animals, length of stay in primary or secondary enclosures, and heat generation of the animals are considerations that must be part of the HVAC design parameters. The ASHRAE Handbook—HVAC Applications has lab descriptions and is a good guide, along with references for design considerations of animal facilities.

Regulations, standards, and good practice design requirements from various organizations must be reviewed and followed as they would apply to the particular application. These include:

- American Association for Accreditation of Laboratory Animal Care (AAALAC)

- Biosafety in Microbiological and Biomedical Laboratories, Centers for Disease Control and Prevention (CDC)
- Institute for Laboratory Animal Resources (ILAR)
- The Animal Welfare Act with authority vested in the U.S. Dept. of Agriculture (USDA)
- Guide for the Care and Use of Laboratory Animals, National Research Council
- Code of Federal Regulations (CFR) 21, Part 58: Good Laboratory Practices for Non-Clinical Laboratory Studies.

Temperature and relative humidity in animal spaces must be flexible and closely controlled to match the research protocol. Temperature ranges between 64 to 85 F are common with a ± 2 F accuracy. Relative humidity ranges of 30% to 60% are considered acceptable.

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An air change rate is a calculation of space volume and airflow which results in the number of minutes it takes for the air to “change.” An example: a 20x20-ft room with a 9-ft ceiling height has a volume of 3600 cubic feet (cf). If the space is supplied with 900 cfm of air, the air would be “changed” every 4 minutes (3600 cf/900 cfm = 4 minutes), which then results in 15 ACH (60 min/hour/4 min). Placement of supply air and air removal devices will determine if all of the air is actually changed. This is part of the overall design challenge.

Air change rates of 10 to 15 ACH have been accepted guidelines to keep odors under control and provide adequate ventilation for high respiration rate animals. While the ACH may be suitable, other factors such as animal heat gain, lights and equipment heat gain, other exhaust requirements (fume hoods), and quantity of animals must be considered to determine correct airflow.

Air distribution device type and delivered air velocity, along with high or low return/exhaust placement, may affect actual ventilation rates or create drafts. Fluctuating animal population may allow for reduced airflow rates while maintaining desired space conditions.

Other spaces and functions generally associated with animal facilities—cage washing, surgery rooms, food storage, treatment rooms, refrigerated storage rooms, and necropsy labs—require careful design, air quantity, filtration, temperature, and relative humidity control. Isolation or quarantine spaces are also found in these facilities and are treated similar to other airborne infectious isolation rooms.

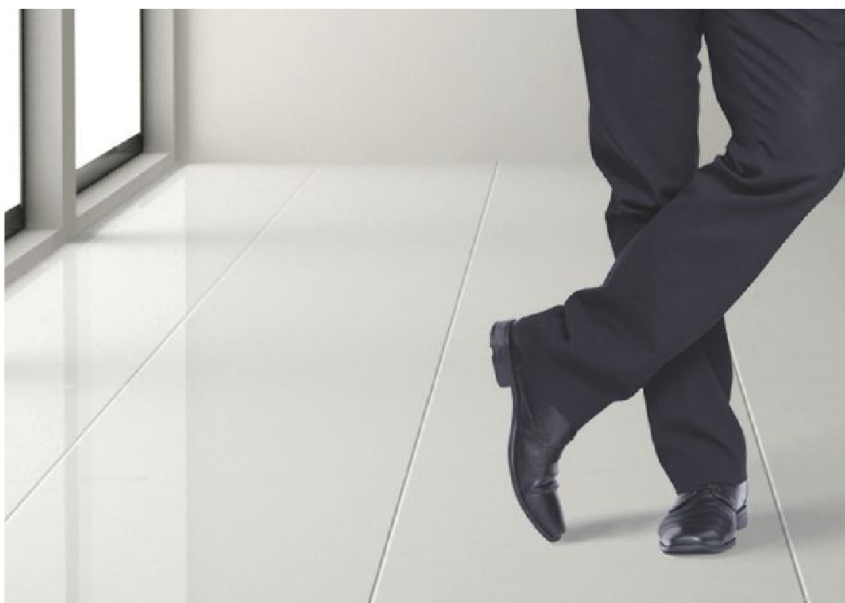
HVAC design for laboratories requires team discussions and planning, identification of design parameters, and adherence to applicable design codes and standards, along with a willingness to agree on the ultimate goals—worker safety, fume and vapor containment and capture, product preservation, and adherence to research protocol. HVAC systems for labs cannot be designed in a vacuum. The more you learn along the way, the better the system design and

layout will become and the better functionality the lab will have. **cse**

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