



# LABORATORIES FOR THE 21<sup>ST</sup> CENTURY: BEST PRACTICE GUIDE

## OPTIMIZING LABORATORY VENTILATION RATES

### Introduction

This Best Practice Guide is one in a series created by the Laboratories for the 21<sup>st</sup> Century (“Labs21”) program, a joint program of the U.S. Environmental Protection Agency and U.S. Department of Energy. Geared towards architects, engineers, and facilities managers, these guides provide information about technologies and practices to use in designing, constructing, and operating safe, sustainable, high-performance laboratories.

Laboratories are highly energy intensive, often using four to six times more energy per square foot than a typical office building. Most existing labs can reduce their energy use by 30 to 50% with existing technology, which is significant given their \$1–2 billion annual energy costs in the U.S. Nearly half of the electrical energy use in a typical laboratory can be attributed to ventilation, and reducing a laboratory’s ventilation needs can lower the cost to build and maintain a facility (see Figure 1).

The objective of this Best Practice Guide is to help users optimize ventilation airflow and reduce associated energy use while maintaining or improving safety. While

this guide highlights best-practice strategies focused on reducing energy use, *it does not specify* how to set a ventilation rate. Note that the terms “good” and “better practices” are used to describe options that improve standard practices.

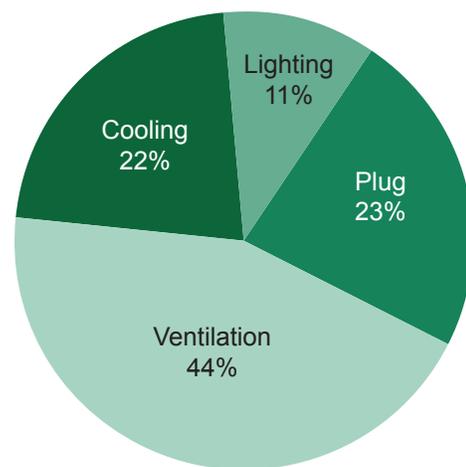


Figure 1. Annual electricity use in Louis Stokes Laboratory, National Institutes of Health, Bethesda, MD.



## Perspective – Standard Practice

In standard laboratory-design practice, ventilation rates are usually derived from guidelines, presented as a range of values in design standards. When using a guideline to determine a ventilation rate for a laboratory, the highest value from the range is often chosen because the guidelines are highly generalized; however, designers should be cautious when using these wide-ranging recommendations. Design firms, or authorities having jurisdiction, typically use a guideline without questioning the true source and the reasoning behind its value. Similarly, designing by only referencing past efforts, by “what’s in the drawer,” limits energy efficiency and may even compromise safety. A simplified “more is better” design approach is not a substitute for due diligence. Ventilation guidelines should only be applied as their authors intended—as ranges, and not as absolutes.

Standard practice also entails the blanket adoption of ventilation guidelines as constant values, with the ventilation rate rarely being dynamically controlled or otherwise tailored to the occupancy or conditions of the site, or optimized for energy efficiency or safety. Some publications simply recommend 4 to 12 air changes per hour. The result can be excessive (or inadequate) ventilation for the lab in question, causing unnecessary energy expenditures. Facility owners also bear the consequences of requiring an unsubstantiated high ventilation rate, inadvertently forcing the engineer to design a potentially wasteful HVAC system.

### Ventilation Codes and Guidelines

After reviewing the user’s program, or design intent document, the project architect determines the laboratory’s occupancy classification. For this resolved occupancy classification, the ventilation rate is provided in a building code specified by the municipality or authority having jurisdiction. The occupancy classification has a significant impact on a building’s energy use. For example, for particularly hazardous occupancy classifications, the ventilation rate is legally stipulated by the applicable building code. However, for less hazardous occupancies, design standards with a range of rates are used only as guidelines for ventilation rates. Note that a design standard may be adopted by the authority having jurisdiction as a “code” requirement.

In the case of building codes for hazardous classifications, ventilation rates are stipulated in terms of floor area as cubic feet per minute (CFM) per square foot, while ventilation guidelines from building design standards for laboratories are based on the total volume of the space and expressed as air changes per hour (ACH), which is how many times the entire air volume in the laboratory is replaced each hour.

Prevailing building codes and design standards provide a context in which best-practice strategies can be implemented. Consider the ventilation guideline provided by OSHA 29 CFR Part 1910.1450, which calls for a range of 4 to 12 ACH for a “laboratory” that often has an occupancy classification of “B.” In contrast, the International Building Code (IBC) (2004) calls for a rate of 1 CFM/ft<sup>2</sup> for an occupancy classification of H-5, which is considered to be a hazardous environment (see Table 1 for this and other examples). Note that for certain quantities of flammable liquids, these must be “used” in a “control area” in order for a building to have a “B” occupancy classification.

As an example of how a code’s ventilation rate (or ambiguity) influences energy use, consider the following two scenarios. One laboratory space, whose occupancy classification is IBC H-5, has a 10-foot-high ceiling and an exhaust airflow rate requirement of 1 CFM/ft<sup>2</sup>; the exhaust airflow from this lab will result in 6 ACH. However, another laboratory space, which has the same floor area but a 15-foot-high ceiling and a “B” occupancy classification, follows the OSHA guideline of 12 ACH and flows three times more air than the higher-hazard H-5 lab. Applying fan-law energy calculations, the “B” lab will consume more than three times the energy of the “H-5” lab. In addition, the first cost of the H-5 lab’s smaller HVAC system will also be less. Note that even though the airflow rate per unit floor area eliminates ceiling height as a determinant of air change requirements, neither the volumetric ACH method nor the area-based CFM method predicts the *effectiveness* of the ventilation.

### Codes

Laboratory designers should study code requirements, understand each classification, be familiar with their potential energy impacts, and relate these findings to the project design team.



Table 1, below, lists typical design codes that are often used as ventilation-rate guidelines:

**Table 1. Common Laboratory Ventilation Rate Codes**

Code	Ventilation Rate	Comment
IBC -2004	1 CFM/ft <sup>2</sup> for H-5	Section 415.9.2.6
IMC - 2004	1 CFM/ft <sup>2</sup>	Rate required for storage areas that exceed maximum allowable quantities of hazardous materials. (Section 502.8.1.1.2)
UBC - 1997	1 CFM/ft <sup>2</sup> for H-6	Uniform codes have been replaced by international codes beginning in 2000. (Section 1202.2.5)

### Standards

Table 2, below, lists common design standards containing guidelines for a laboratory’s ventilation rate:

## Standard Practice — More Is Not Necessarily Better

While “rules of thumb” often dictate that “more is better,” i.e., that increased ventilation rates yield increased safety, worker comfort, and research productivity, real-world experience shows that this is not the case. In fact, excessive ventilation can diminish safety conditions in labs that use hazardous and odorous materials as part of their experimental studies (see sidebar on “Ventilation Dilution”). Thus, best practices *optimize* rather than *maximize* ventilation, and consider the “mixing factor” of the pollutant being removed from the lab.

**Table 2. Common Laboratory Ventilation Rate Standards**

Standard	ACH Number	Comment
ANSI/AIHA Z9.5	The specific room ventilation rate shall be established or agreed upon by the owner or his/her designee.	The latest version of the American National Standards Institute and the American Industrial Hygiene Association standard (ANSI/AIHA Z9.5-2003, Section 2.1.2) states that a method based on “air changes per hour is not the appropriate concept for designing containment control systems. Contaminants should be controlled at the source.” ANSI/AIHA also states that the air changes per hour do not “reflect actual mixing factors” of a particular room.
NFPA-45-2004	Minimum 4 ACH unoccupied; occupied “typically greater than 8 ACH.”	According to the National Fire Protection Association’s Standard NFPA 45, Appendix A: A8-3.5 (NFPA 45 2004), room air currents in the vicinity of fume hoods should be as low as possible, ideally less than 30% of the face velocity of the fume hood. Air supply diffusion devices should be as far away as possible from fume hoods and have low exit velocities.
ACGIH–Ind. Vent.– 24th Ed.–2001	The required ventilation depends on the generation rate and toxicity of the contaminant, not on the size of the room in which it occurs.	This standard from the American Conference of Governmental Industrial Hygienists states that “‘Air changes per hour’ or ‘air changes per minute’ is a poor basis for ventilation criteria where environmental control of hazards, heat, and/or odors is required.” The impact of the laboratory’s ceiling height is identified as one reason why an air change approach does not adequately address the required contamination control (Section 7.5.1, Air Changes).
ASHRAE Lab Guide–2001	4-12	The ASHRAE Laboratory Design Guide includes suggestions relating to the following: <ul style="list-style-type: none"> <li>• Minimum supply air changes</li> <li>• Minimum exhaust air changes</li> <li>• Minimum outdoor air changes</li> <li>• Recirculation considerations</li> </ul>
OSHA 29 CFR Part 1910.1450	4-12	The Occupational Safety and Health Administration specifies a room ventilation rate of 4 to 12 air changes per hour, which “is normally adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control.” This range is extremely broad and provides a designer with little guidance.

Studies of laboratory facilities have demonstrated that the room air change rate has less effect than a room air diffusing system or other ventilation characteristic on environmental conditions. Designers need specifications that are tailored to a laboratory's air circulation arrangement, because many conventional design parameters and recommendations should not be universally applied; for example, they may not relate to microenvironmental (e.g., cage) conditions in a laboratory (Zhang et al., 1992; McDiarmid, 1988).

Other studies show that air dilution or replacement does not protect personnel from exposure to concentrated bursts of aerosols in biological laboratories. For example, Crane (1994) quotes Chatigny and West (1976), who say that "increasing ventilation rates from 6 to 30 air changes per

hour (ACH) has a minimal effect on aerosol concentration of microorganisms in the first few minutes after release."

Adjusting ventilation is not the only way to control environmental conditions. For instance, Memarzadeh (1999) has shown that controlling the humidity in animal rooms is more effective than using high air change rates in managing the production of ammonia from animal urine. This has allowed users to decrease "the air change rate from 15 to as low as 5, while improving the welfare of the animals."

## Preparation — Process Overview

Determining a laboratory facility's ventilation rate is not an exact science; therefore, a "precise" answer cannot be the only goal of the ventilation system designer. More important is the process carried out by the ventilation system designer to resolve an appropriate ventilation rate. At the initial (conceptual) level, the designer should consider the following four-step process:

### Step 1: Review Design Intent

Study and support the features embodied in the facility's design intent document. The document should include three main categories, which are followed by the designer's actions:

- **User programming:**
  - Characterize the building's mission.
  - Differentiate between "needs" and "wants."
  - Evaluate client statements.
  - List research goals.
- **Occupancy classification:**
  - Interpret municipality's building code.
  - Determine occupancy classification requirements.
  - Analyze energy-use impacts.
  - Relate findings to the project design team.
- **Essential building functions and systems:**
  - Identify architectural features.
  - Evaluate engineering approaches.
  - Itemize main design elements and characteristics.
  - Determine "boundaries" for design.

#### Ventilation Dilution\*

The principal device used to contain harmful emissions from chemicals within a laboratory is the chemical fume hood. Such hoods come in various sizes, but a typical internal working surface dimension is 66 inches wide and 26 inches deep. If one assumes an 18-inch sash opening, and an average face velocity of approximately 100 fpm, approximately 850 cfm of air is induced through the hood by the laboratory exhaust system. Furthermore, for hoods designed in accordance with the guidance provided in Appendix A.6.4.6, NFPA 45-2000, a minimum of 300 cfm of dilution air is admitted when the sash is fully closed. For laboratory ventilation systems designed in accordance with the guidance provided in Appendix A.6.3.5 of NFPA 45-2000, room air current velocities in the vicinity of the hood should ideally be less than 30 fpm.

Given the hood dimensions and ventilation system design guidance described above, consider an accidental one-liter spill of hydrogen fluoride or hydrogen chloride in the vicinity outside of the fume hood. In calculating the concentrations resulting from either of these spills, it can be shown that the contaminant threshold limit value IDLH—Immediately Dangerous to Life and Health—is exceeded regardless of sash position. Additional results are summarized below:

- If room air current velocities in the vicinity of a hood are increased above the minimum recommended level (as noted above), emission rates from the spill increase, as do the resulting concentration levels of contaminants in the air flowing toward the fume hood.
- If the volumetric airflow rate in the vicinity of the hood is increased, as in the case of opening the sash of a variable air volume (VAV) hood, lower concentration levels result.
- Unfortunately, ventilation airflow rates have to increase by at least one or two orders of magnitude above those induced through the fume hood to keep from exceeding life-threatening threshold levels. Furthermore, ventilation systems designed to provide such airflow rates are impractical because they are physically constrained by the size of the building.
- Consequently, ventilation dilution is not the solution to pollution resulting from an accidental spill of hazardous chemicals within a laboratory.
- Finally, the above results point to the importance of handling chemicals safely before delivering them to chemical fume hoods.

Note: IDLH was established by the National Institute for Occupational Safety and Health. It is defined as the concentration of airborne contaminant that poses a threat of death, immediate or delayed permanent adverse health effects, or effects that could prevent escape from such an environment.

\*Courtesy of John L. Peterson, P.E., Office of Facilities Planning and Construction, University of Texas System

## Step 2: Identify Authority Having Jurisdiction

Ensure that the authority is identified and involved, and has a clear understanding of the difference between codes and standards:

- **Codes:**
  - Have “force of law.”
  - Are restrictive.
  - Require compliance.
- **Standards:**
  - Are open to interpretation.
  - Have a wide span of acceptable values.
  - Are subject to manipulation.
- **Adopted standards:**
  - May be based on sound judgment.
  - Could be biased or reflect entrenched doctrine.
  - May be archaic and not reflect latest technology or practices.

## Step 3: Assess Priority and Resources for Optimizing Ventilation Rates

- Garner team support to optimize laboratory ventilation rate during design charrette.
- All stakeholders identify lab’s design goals and issues.
- Promote fundamental impact of lab’s ventilation rate on:
  - Continuous safety performance.
  - Immediate HVAC first-cost.
  - Long-term energy use.
- **Consider:**
  - Scope: Owner’s priorities.
  - Schedule: Available time.
  - Budget: Value engineering.

## Step 4: Implement a Design Strategy

Once steps 1 through 3 have been completed, implement the appropriate design strategy:

- A design strategy can be chosen from one of the following three options:

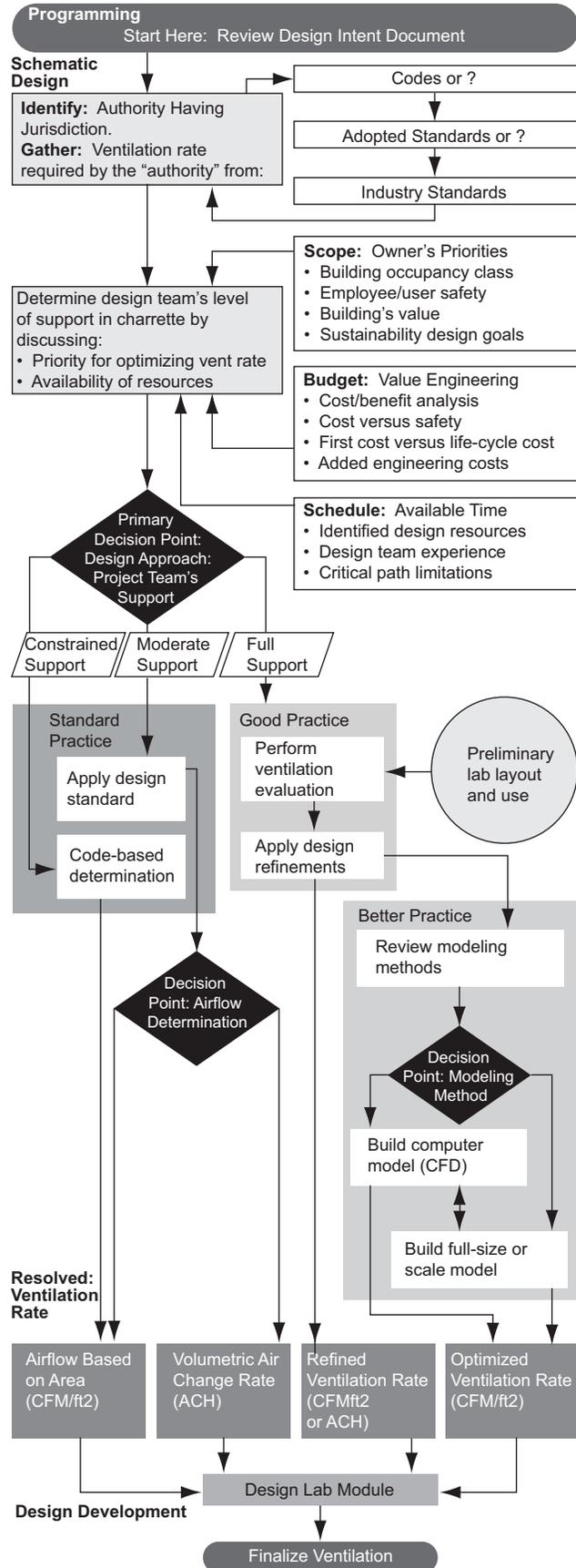


Figure 2. Process flowchart.



- Constrained design: Restricted, or constrained by building code.
- Standard design: Conventional practice that employs design standard's guidelines.
- Optimized design: See following details.

If an optimized design strategy is chosen, a design team's support must balance scope, schedule, and budget limitations with "attitude" and "resources." The following should be considered by the design team:

- **Optimized design support requires a change in attitude:**
  - Do not impose standard or usual policies and methods.
  - Willingly provide information on experimental procedures.
  - Remain open and flexible to new ideas and alternate ways of doing science.
- **Optimized design support needs to be quantified:**
  - Use life-cycle costing as a measurement tool for decision making.
  - Establish project schedule and project costs, and get designer's concurrence.

## Implementation — Strategies to Optimize Lab Ventilation

There are many design factors to consider when optimizing lab ventilation. These include the lab's layout (e.g., arrangement of equipment) and use (potential pollutants), control and removal of hazardous pollutants, and how to achieve adequate ventilation while attending to cooling load requirements.

The "good" and "better" practices outlined below begin with codes or standards as a starting point for designs, while facilitating the adoption of ventilation specifications that ensure safety and energy efficiency. Good practices emphasize lab-specific operations and control strategies, while better practices improve the ventilation design process with advanced computer or physical modeling techniques. These new techniques evaluate scenarios in which the system will need to respond to critical conditions (e.g., hazardous material spills, pollutant mixing

factors), thereby reducing the guesswork involved in standard practice, and ensuring that the facility will perform well during emergencies.

## Good Practice Strategies: Control Refinements

As with most pollution-abatement strategies, the most effective strategies begin with source control, containment, and minimization. Ventilation is not a substitute for poor practices in handling hazardous materials, but the following control refinements can help maximize the effectiveness of ventilation while keeping energy costs in check:

- **Occupancy control**
- **Demand control**
- **Hazardous banding control**
- **Task ventilation control (localized exhaust ventilation, LEV)**

### Occupancy Control — Occupied versus Unoccupied Ventilation Rates

The differences in ventilation requirements between occupied and unoccupied modes should be considered. The *ASHRAE Laboratory Design Guide* suggests that setback control strategies can be used in laboratories to reduce air changes hourly during unoccupied periods, e.g., at night and on weekends. The NFPA 45 Standard recommends a minimum ventilation rate of 4 ACH for unoccupied laboratories; some labs are designing for even lower rates.

### Demand Control — Emergency Override Ventilation

Emergency override is a design refinement of the laboratory's supply and exhaust system to provide increased airflow and negative pressurization in an emergency. Such a design can reduce both energy use and first cost, unlike designs for continuous operation under rare worst-case conditions. Emergency push-button overrides can be located near fume hoods and at the lab's entrance(s), and should come equipped with indicator lights and audible alarms. The facility's automated control system can:

- **Increase airflow through the lab during an emergency.**
- **Notify the facility's Environment, Health, and Safety (EH&S) staff.**
- **Discourage other workers from entering the laboratory.**

Demand-controlled ventilation (DCV) is an emerging technology that utilizes pollutant sensors in order to provide real-time variable-air-volume ventilation control. DCV differs fundamentally from typical practice, which “blindly” sets a fixed ventilation rate based on anticipated (but not verified) pollutant levels. Some key challenges in DCV design are correct sensor choice and placement.

A notable benefit of DCV—in addition to energy savings—is the introduction of monitoring equipment that can detect hazards and provide alarms and reporting. In addition to monitoring for spills and other accidents, DCV can also help identify malfunctioning fume hoods or poor lab practice (e.g., chemicals left out of fume hoods) that could otherwise go undetected.

### Hazardous Control Banding: Classifying Chemicals and Hazards

Control banding is a strategy for classifying and handling chemicals and hazards according to their associated health risks. A control band score is calculated by weighing a chemical’s level of toxicity, scale of use, and ability to become airborne under certain conditions. The control band score directs the user to appropriate control strategies. (See sidebar on “Control Banding.”)



#### Control Banding for Optimizing Laboratory Ventilation Rates\*

Control banding is a means of classifying and grouping substances used in a process or activity by health risk for the purpose of determining an appropriate control strategy. Risk is most often described as a function of the likelihood and consequences of an event. For control banding, chemical classification has a similar risk basis. Toxicity (with consideration of the potential for skin absorption) is a measure of the consequence of exposure. The scale of use (quantity) and the ability to become airborne (volatility for liquids, or dispersibility for solids) are measures of the likelihood of exposure. Combinations of the different levels of toxicity, scale of use, and ability to become airborne under the conditions of use yield a score that equates to a control band. The control band, combined with the tasks involved, directs the user to the appropriate control strategies. Strategies are based on four key approaches:

- Employ good industrial hygiene practice;
- Use local exhaust ventilation;
- Enclose the process; or
- Contact a professional industrial hygienist.

The control-banding concept can easily be applied to laboratory chemical operations, where the chemical use quantities tend to be small, and chemical toxicity and ability to become airborne vary widely with the chemicals of interest. For a specific process and associated chemicals, the control band might specify activities permitted with various room air change rates, activities that require local ventilation, and activities that must be conducted in a fume hood at various flow rates, with the highest risk at hood flows set for optimum containment of airborne contaminants. A laboratory might have airflows optimized to do work only up to a certain control band, or specific hoods might be designated for work within a certain control band, based on airflow and contaminant containment.

Courtesy of John Piatt, Pacific Northwest Laboratory

Control banding can be applied to laboratory chemical operations. For a specific process and associated chemicals, the control band can specify what activities are permissible at a room air change rate, require local ventilation, and must be conducted in a fume hood at a particular flow rate. (Chemicals with the highest risk are handled at hood flows set for optimum containment, or performed in a glove box.) A laboratory might optimize airflows for work up to a prescribed control band, or designate specific hoods, based on airflow and contaminant containment, for work within a certain control band.

This new approach to classifying chemical hazards is being increasingly applied worldwide. For example, the United Kingdom has incorporated control banding into its recommended tools for compliance with regulations by the Control of Substances Hazardous to Health.

During the design of a new lab building and retrofit of an existing one, the University of Rochester (UR) recently used control banding to identify a hazard level for each of its labs. After performing a detailed review and analysis of hazards being used in the university’s labs, the UR Health and Safety Officer used control banding to create a new air change rate standard. Based on this approach, an “A” lab has 8 ACH when it is occupied, and 6 ACH when unoccupied (8/6 ACH); a “B” lab has 6/4 ACH, and a “C” lab has 4/2 ACH. Control banding can also be done on a basis of CFM/ft<sup>2</sup>.

In the example of the University of Rochester, the use of control banding is a step in the right direction, but it still reinforces the conventional wisdom that “more is better.” As described later, better ventilation design and evaluation strategies will provide greater protection from airborne chemical hazards than simply increasing air change.

### Task Ventilation Control

Special-purpose laboratories provide an opportunity for designers to apply localized ventilation devices suited for a lab’s particular use. Examples include animal labs using cage ventilation as a task-specific ventilation or local exhaust ventilation (LEV) strategy, electronic clean rooms using mini-environments, or biomedical labs using biological safety cabinets (BSCs).

In the case of animal labs, studies such as those by Memarzadeh (1999) have shown that increasing a room’s ventilation rate does not have a significant effect on cage ventilation. In addition, Riskowski et al. (1996) identified cage *type* as an important factor in determining the ventilation rate in an animal facility, and Zhang et al.



(1992) found that providing a quality environment for animal studies “was more dependent on cage design, room ventilation system design, and animal management practices than on room air exchanges.”

Good practice therefore involves tailoring ventilation to a specific “task,” and to a location within a laboratory equipped with LEV. When this is done, general ventilation rates may be relaxed without compromising safety or comfort at the location of the task. Note that LEV systems can increase energy use if improperly designed, installed, or operated due to high ventilation system pressure drop requirements, leaking devices, and “open” unused LEV devices.

## Better Practice Strategies: Simulation Methods

In an effort to optimize ventilation system layouts and laboratory designs, better-practice strategies apply real or virtual laboratory models that permit airflow pattern simulations. These performance-based approaches evaluate a simulated environment’s hazards, e.g., they determine a chemical’s clearing time by calculating the lab space’s “mixing factors” for a given spill scenario rather than simply applying a universal, prescriptive air change rate. This is an iterative process that accounts for facility design features that influence one another. The following simulation methods may be applicable:

- CFD simulations
- Tracer gas simulations
- Neutrally buoyant bubble simulations

### Computational Fluid Dynamics (CFD) Simulations

For this better-practice approach, a geometric representation of the lab space is “built” within a computer. Then, a simulation of the airflow patterns inside the lab is modeled using a computational fluid dynamics (CFD) computer program. Results from the model help designers determine a lab’s airflow characteristics by:

- Developing “answers” to spill scenarios.
- Estimating residence time of a hazard.
- Evaluating the placement of major design elements, such as hoods, benches, registers.

- Eliminating stagnant dead zones in which air recirculates or there exist “lazy” airflow patterns.
- Examining numerous “What if?” scenarios.

This virtual model can also be the basis of a full-scale construction of a laboratory space.

CFD simulation methods can help determine the lab’s airflow characteristics, spill clearing performance, and mixing factors including removal of fugitive emissions, e.g., small continual releases from an evaporating solvent in an uncovered beaker outside a fume hood. Importantly, CFD models can predict plume patterns of spill scenarios, and the required “clearing time” following a spill *before* it happens.

CFD modeling methods are useful for evaluating the dynamic effects of HVAC system features, layout, and operation. Room geometry, HVAC system equipment, diffuser placement, and laboratory equipment as well as operational procedures all influence air movement in the laboratory, particularly around the fume hood sash opening. A CFD model simulates the interaction of all of these variables—as well as the turbulence caused by a worker’s movements—to provide data that can be used to understand a laboratory’s temperature, air movement, relative pressure, regions of turbulence, and contaminant concentrations. In addition, this modeled information can be further analyzed to study fume hood containment capabilities, challenges to the hood’s containment, e.g., supply temperature variations, residence time of air moving through the modeled lab, placement of ventilation inlets and outlets, and other factors.

Although costly, building a full-scale model of a laboratory module can be justified when the module will be replicated many times in one facility or in multiple facilities. Performance-design methods including pre-construction CFD modeling and full-scale lab modeling, followed with *in situ* evaluations, can make laboratories safer and more energy efficient.

### Tracer Gas Simulations

Once a scaled or full-size mockup is built, a lab’s ventilation system can be determined by using a tracer gas test, according to the *ASHRAE Laboratory Design Guide*. The tracer gas is evenly distributed throughout the laboratory, and the rate of decay in the tracer gas concentration is used to calculate air changes per hour (ACH). To imple-

ment this strategy, sensors are installed in the room, a tracer gas is introduced, and ventilation rates are increased until the desired rate of decay is obtained. (EH&S specialists typically determine the appropriate rate of decay.)

### Neutrally Buoyant Helium Bubble Simulations

Using neutrally buoyant helium bubbles to study airflow patterns in a laboratory space (see Figure 3) is a relatively new method. Tiny helium-filled bubbles about one-eighth of an inch (2 mm) in diameter are generated at the rate of approximately 400 bubbles per minute. These bubbles quickly reach room temperature and follow the slightest air current in the room. They persist for up to two minutes, providing designers an opportunity to study a lab's ventilation system. Helium bubbles are also useful for evaluating the efficacy and placement of supply diffusers and return air grilles; their positions can be varied during the test in order to mitigate areas of stagnant air.

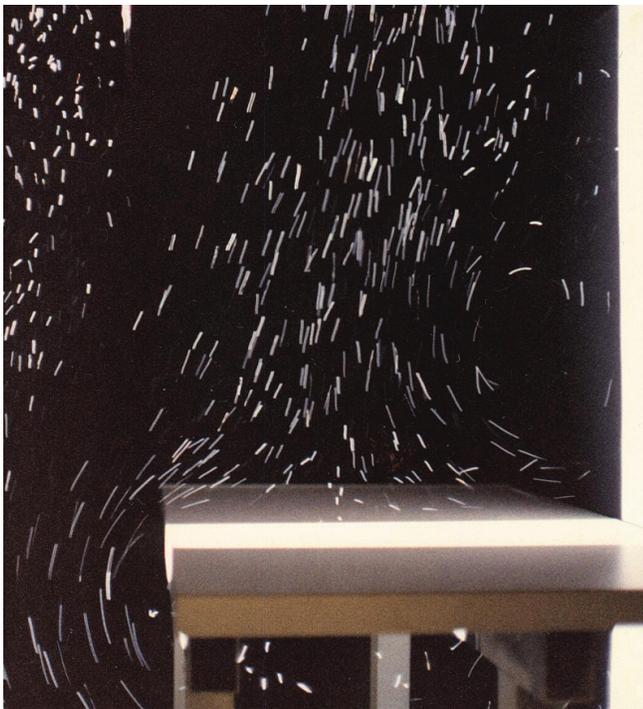


Figure 3. A laboratory's airflow pattern shown by neutrally buoyant helium bubbles.

## Meeting the Challenge — Performance Examples

### Princeton University, Guyot Hall

In this example (see Figure 4), CFD models were used to evaluate teaching and research labs at Princeton University's Guyot Hall. Results from the CFD models allowed the design team to evaluate risks and reduce operating costs, and thus enhance the performance of the Princeton researchers' laboratories. Using the CFD model to study different ventilation rates provided a greater understanding of the ability to remove airborne pollutants from these labs. Thanks to improved information provided by the CFD analysis, the initial mandated rate of 10 ACH was reduced to 8 ACH during occupied periods, and lowered to 6 ACH during unoccupied periods, while an "emergency" rate of 10 ACH was designed into the HVAC system.

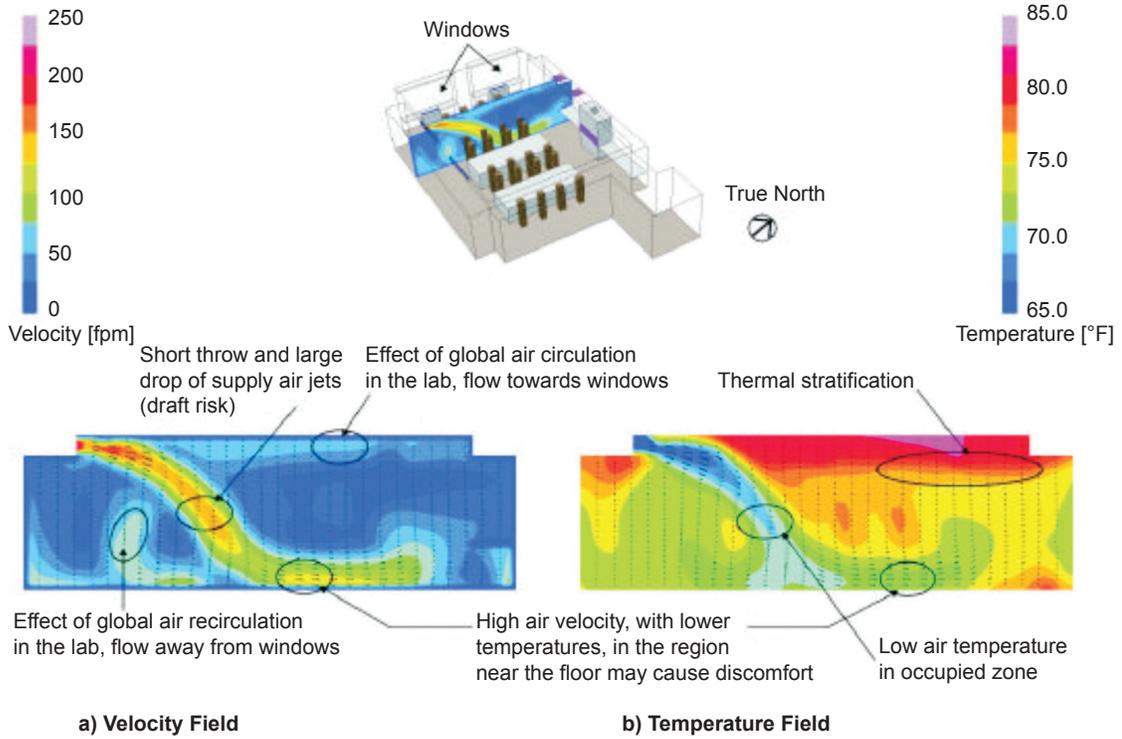
### Wyeth Research and Development Laboratory

In this example (see Figure 5), the design team built a CFD simulation of Wyeth Laboratory's new Viral and Immunology Research Laboratory.<sup>1</sup> The main concern was determining the optimal air change rate, since available standards and guidelines only provide a wide range of rates that are not immediately applicable to the specific research mission of this new lab. The CFD evaluations helped show that an air change rate of 8 per hour was more effective in containing and removing pollutants than the "required" rate of 12 ACH, which was accepted by the authority having jurisdiction.

Various "spill scenarios" were modeled and evaluated for transient concentration levels. The CFD model helped designers characterize how an optimal layout of the ventilation system can improve worker safety by effectively removing spills. It also indicated that a lower air change rate was potentially more effective than a higher ventilation rate in removing spills, thus potentially reducing annual energy costs by \$280,000.

<sup>1</sup> For additional information, see [http://labs21.lbl.gov/DPM/Assets/e3\\_maine.pdf](http://labs21.lbl.gov/DPM/Assets/e3_maine.pdf).





Contours of Temperature and Velocity Profile Teaching Lab, Scenario 1 Interior Air Flow Analysis Guyot Hall Addition at Princeton University	Scale: N.T.S.	<b>RWDI</b>
	Date revised: April 29, 2002	

Figure 4. Guyot Hall CFD model.

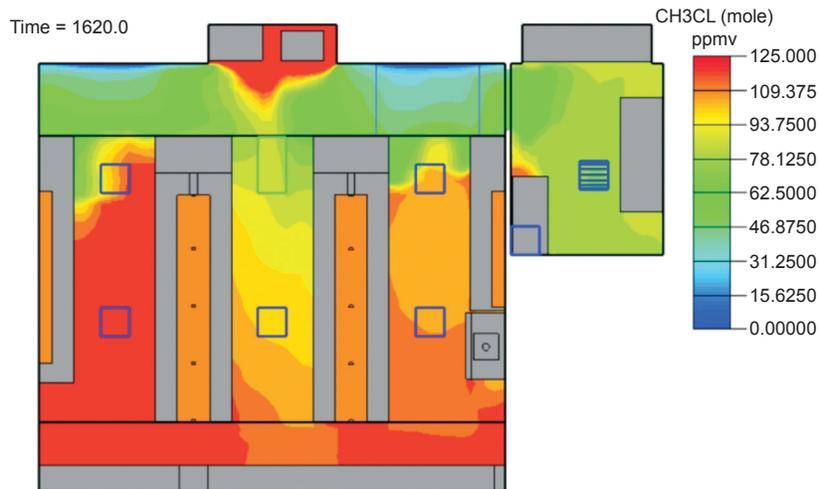


Figure 5. Wyeth Labs CFD model "snapshot."

## Performance Assurance — Commissioning

Commissioning is an optimization process that ensures the ventilation system's design intent is achieved in practice. According to Bell (2006), a key initial step in commissioning is to compare the expected use (at the time of design) to the actual use (at the time of commissioning), and to the reasoning behind ventilation levels and strategies stipulated in the original design. Methods for detecting faults in ventilation system operation range from design review to functional testing of equipment, sensors, and controls. A survey of commissioning experience nationwide found that ventilation systems were the most frequent source of performance problems, and that laboratories achieved greater benefits (higher energy savings and shorter payback times) from commissioning than any other building process (Mills et al., 2004).

Where new technology is applied in order to attain given performance levels, e.g., sensors and variable-speed drives for demand-controlled ventilation, the equipment itself also must be commissioned to ensure that it is performing as intended.

Ventilation-related devices that should be checked for proper performance and accuracy are as follows:

- Supply air temperature sensors placed upstream and downstream of any reheat coil.
- Volumetric airflow meter/devices.
- Pressure differential monitor for lab space with reference to "cleaner" space.
- Stack exit velocity meter.
- Supply and exhaust duct static pressure.
- Variable speed drive (VSD) readings.
- Laboratory equipment process load and lighting load.
- Energy recovery systems, when present.

A recommended procedure in ANSI Z9.5-2003, the System Mode Operational Test (SMOT), should be part of a "good practice" effort. This test procedure is a system-wide functional verification that examines how well all of the individual lab components and design features work together as a whole. Adequate and measured responses by the central HVAC system to normal lab operations are evaluated during a SMOT. An HVAC system must respond directly to actions performed in a lab space, e.g., How

precisely does the HVAC system airflow respond to a lab fume-hood sash being operated, or How exactly is the lab room pressure differential maintained during a door-opening sequence? In addition to possible safety breaches, the inability of an HVAC system to respond to changes in a lab's environment directly translates into energy being wasted, often in excess of 20%.

## Conclusion

Standard ventilation design practice optimizes neither safety nor energy efficiency. While predefined code- or standards-based designs are the most straightforward approaches, they do not optimize a laboratory's ventilation rate, or verify whether the intended levels of safety and comfort have been achieved by the lab's design. Good and better ventilation design practices, which involve in-depth analyses of a researcher's task, the location of a task within a laboratory, and more coordinated exposure assessments to characterize risks, translate into higher energy efficiency, lower life-cycle cost, and, most importantly, enhanced safety.

## References

- Barkley, W.E. "Issues in laboratory ventilation for hazard control," *Proceedings of the Symposium on Laboratory Ventilation Hazard Control* (Frederick, MD, 1976).
- Bell, G.C., E. Mills, D. Sartor, D. Avery, M. Siminovitch, M.A. Piette. *A Design Guide for Energy-Efficient Research Laboratories*, LBNL-PUB-777, Lawrence Berkeley National Laboratory, Center for Building Science, Applications Team, September 1996–2003.
- Bell, G. "Retrocommissioning Laboratories for Energy Efficiency," *Laboratories for the 21st Century, Technical Bulletin*, 2006.
- Crane, J.T. "Biological Laboratory Ventilation and Architectural and Mechanical Implications of Biological Safety Cabinet Selection, Location, and Venting," *ASHRAE Transactions*, 100(1):1257–1265, 1994.
- Maghirang, R.G., G.L. Riskowski, L.L. Christianson, L.L. "Ventilation and Environmental Quality in Laboratory Animal Facilities," *ASHRAE Transactions*, 102(2):186–194, 1996.
- Marshall, J.W. "Health Care Ventilation Standard: Air Changes per Hour or CFM/Patient?" *ASHRAE Journal*, 38(9): 27–30, September 1996.
- McDiarmid, M.D. "A Quantitative Evaluation of Air Distribution in Full Scale Mock-Ups of Animal Holding





Rooms." *ASHRAE Transactions*, 94(1): 685–693, 1988. (This article also appears in *Laboratory HVAC*, 1995, 89–94, ISBN 1-883413-25-7.)



Memarzadeh, F. "Of Mice, Men, & Research." *Engineered Systems*, 16(4), April 1999.



Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M.A. Piette. *The Cost-Effectiveness of Commercial-Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States*. Lawrence Berkeley National Laboratory Report No. 56637, 2004.



Riskowski, G.L., R.G. Maghirang, W. Wang. "Development of Ventilation Rates and Design Information for Laboratory Animal Facilities. Part 2 - Laboratory Tests." *ASHRAE Transactions*, 102(2): 195–209, 1996.

Zhang, Y., L.L. Christianson, G.L. Riskowski, B. Zhang, G. Taylor, H.W. Gonyou, P.C. Harrison. "A Survey of Laboratory Rat Environments." *ASHRAE Transactions*, 98(2): 247–253, 1992.

## Acknowledgments

### Author

Geoffrey C. Bell, P.E., M. Arch.  
Lawrence Berkeley National Laboratory

The author is very grateful to the following people for their important contributions and thoughtful reviews:

- John Piatt, P.E., Pacific Northwest National Laboratory
- John Peterson, P.E., University of Texas System
- Otto Van Geet, P.E., National Renewable Energy Laboratory
- Paul Mathew, Ph.D., Lawrence Berkeley National Laboratory
- Lou DiBerardinis, Massachusetts Institute of Technology



## For More Information



### On Optimizing Ventilation Systems

Geoffrey C. Bell, P.E., M. Arch.  
Lawrence Berkeley National Laboratory  
One Cyclotron Road, MS 90-R3111  
Berkeley, CA 94720  
510-486-4626  
GCBell@lbl.gov



### On Laboratories for the 21st Century

Dan Amon  
General Engineer  
OARM/OA/FMSD/Sustainable Facilities Practices  
Branch  
U.S. Environmental Protection Agency  
1200 Pennsylvania Ave., N.W. (mail code 3204R)  
Washington, DC 20460  
202-564-7509  
amon.dan@epa.gov

Will Lintner, P.E.  
U.S. Department of Energy  
Federal Energy Management Program  
1000 Independence Ave., S.W.  
Washington, DC 20585-0121  
202-586-3120  
william.lintner@ee.doe.gov

### Best Practice Guides on the Web:

[http://www.labs21century.gov/toolkit/bp\\_guide.htm](http://www.labs21century.gov/toolkit/bp_guide.htm)



### Laboratories for the 21st Century

U.S. Environmental Protection Agency  
Office of Administration and Resources Management  
[www.epa.gov/labs21century/](http://www.epa.gov/labs21century/)



In partnership with the  
U.S. Department of Energy  
Energy Efficiency and Renewable Energy  
Federal Energy Management Program  
[www.eere.energy.gov/femp](http://www.eere.energy.gov/femp)

September 2008

Prepared at the  
National Renewable Energy Laboratory  
A DOE national laboratory

Printed with a renewable-source ink on paper containing at least  
50% wastepaper, including 20% postconsumer waste