FEATURE

Identifying general laboratory ventilation requirements using a control banding strategy

In a previous article,[1] we described how we used two ANSI standards (Z10 and Z9.5) to develop an institutional Laboratory Ventilation Management Program (LVMP). This paper describes our use of a control banding strategy as a key tool in this LVMP to establish target ventilation rates for specific laboratory spaces. In spaces where chemicals are used consistent with OSHA's definition of laboratories, Cornell University in Ithaca, NY uses a default rate of 8 air changes per hour (ACH) when the lab is occupied and 4 ACH when the lab is unoccupied. The primary alternative control band for laboratory ventilation, when conditions allow, is 6 ACH (occupied) and 3 ACH (unoccupied). These ranges are used when three operating conditions are met: volatile chemical sources are controlled by local ventilation; the ventilation effectiveness within the laboratory prevents accumulation of significant concentrations of chemical vapors; and laboratory housekeeping is adequate to avoid ongoing sources of fugitive emissions in the laboratory. In this process, we also identify laboratory chemical uses that lie outside these control bands; these require specialized review to determine appropriate ventilation rates.

By Ellen Sweet, Ralph Stuart

INTRODUCTION

Previously we described the conceptual basis for the development of a Laboratory Ventilation Management Plan for Cornell University's Ithaca campus.[1] This LVMP balances two goals of laboratory ventilation: (1) the health and safety of laboratory workers and (2) the long-term environmental sustainability of laboratory facilities, particularly with regard to energy use. The LVMP describes the roles of a variety of stakeholders in identifying and implementing energy conservation opportunities relative to laboratory ventilation.

General laboratory ventilation rates are an energy use concern because the air supplied to the room is single-pass air that is immediately exhausted from the building, as it is possibly contaminated with chemical vapors. Reducing the amount of air used for general laboratory ventilation increases the sustainability of laboratory work by reducing the financial and environmental costs associated with it, but it also raises concerns about the buildup of emissions in the laboratory. This article describes one of the key tools for the Environmental Health and Safety staff in addressing this concern: control banding of general laboratory ventilation rates within Cornell facilities. We have visited over 1000 laboratory rooms at Cornell to perform these assessments. In about 80% of these visits we have found that a lowered ventilation rate is adequate to prudently manage health and safety concerns in the laboratory while improving energy performance. These laboratories have primarily been in the life sciences.

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THE CHALLENGE OF ASSIGNING GENERAL VENTILATION RATES IN LABS

General laboratory ventilation relies on dilution of contaminants to prevent accumulation of flammable levels of vapors, to control odors, and avoid the buildup of toxic levels of chemicals.[2] This strategy is most effective when specific sources of chemical emissions are controlled by local containment devices such as fume hoods or localized exhaust points. In laboratories, general ventilation is intended to control small sources of volatile chemicals, such as exhaust from instrumentation or bench top use of small amounts of chemicals. However, there are three important challenges in using general ventilation as a protective strategy in the laboratory.

The first challenge is that, by definition, laboratory operations use a wide variety of chemicals in changing amounts and concentrations on an irregular basis. Therefore, the risks associated with airborne chemicals in the laboratory change irregularly. With this in mind, it is tempting to try to organize ventilation of laboratories based on their design intent (e.g., wet or dry labs) or a generic description of the science conducted there (e.g., biochemistry, engineering or molecular biology). Unfortunately, we have found that laboratory work within these classifications is not organized around the chemical hazards associated with the scientific work. Rather, laboratory work is more likely to be organized around the personnel of specific lab groups, their fields of research

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interest, and the processes involved in conducting their science rather than around the chemical hazards associated with this work. Additionally, scientific work is becoming increasingly multi-disciplinary, which means that the use of hazardous chemicals can show up in unexpected places. For these reasons, we have found that it is not uncommon to find a small, but significant, number of laboratories in specific departments that use chemicals more intensely than the rest of the department.

Adding to this concern is the fact that during the design of laboratory buildings, the future use of each lab space is often unknown. These uses are likely to change over the life of the building as research progresses, scientific techniques change, and the institution's research agenda adapts to those changes. For this reason, we believe that it is necessary to evaluate laboratory ventilation needs on a laboratory-by-laboratory basis.

A second important challenge is that general ventilation operates most effectively when it moves air through the room as smoothly as possible from the supply air diffusers to exhaust points (i.e., it approaches laminar flow). At Cornell, we have found that many laboratory designs do not achieve this, resulting in areas in and near the laboratory where chemical contaminants accumulate. Such areas may only become evident after research groups have occupied spaces and set up work stations with equipment that interferes with proper airflow. For this reason, it is important to review airflow patterns in active laboratories to identify situations that might result in locations within the room where the ventilation is less effective, resulting in elevated airborne chemical buildup.

The third challenge is laboratory housekeeping. We have observed that fugitive emissions in laboratories are not limited to instrumentation and bench top processes, but can also result from long term storage of containers of volatile chemicals or the off-gassing of residues of chemical spills and other long term releases that have not been well managed by lab occupants. The high general ventilation rates associated with laboratories can often obscure these fugitive releases which can become more evident when the ventilation rate is reduced.

We believe the most prudent approach to these challenges is to have a person familiar with both laboratory chemical hazards and the principles of laboratory ventilation review laboratory spaces to assign an appropriate ventilation rate based on these factors. This is most likely to be the "responsible person" named in the institutional Laboratory Ventilation Management Plan described by ANSI Z9.5. At Cornell, this person is the University Chemical Hygiene Officer or their designee. In a large research institution, there are thousands of laboratory rooms to be visited for this purpose. In order to assure consistency and reproducibility in making general ventilation recommendations, we have developed an assignment process based on the control banding paradigm. The logic of this strategy is outlined in Figure 1.

THE CONTROL BANDING STRATEGY

As described above, chemical processes and experiments can be expected to change irregularly in the academic laboratory setting. For this reason, complete and current inventories of the chemicals used in a particular laboratory are not always available. However, the general hazard classes of chemicals and types of chemical processes used in many academic laboratories are limited and stable enough to be able to make broad assessments of chemical risks and then assess the general ventilation needs to control those risks. This approach enables general ventilation rate assignments to take advantage of the control banding strategy developed for other health and safety applications.

"Control banding" is a system for assigning generic protection strategies to similar hazards based on a risk assessment of specific instances of those hazards. The hazards are grouped into "bands" that can be

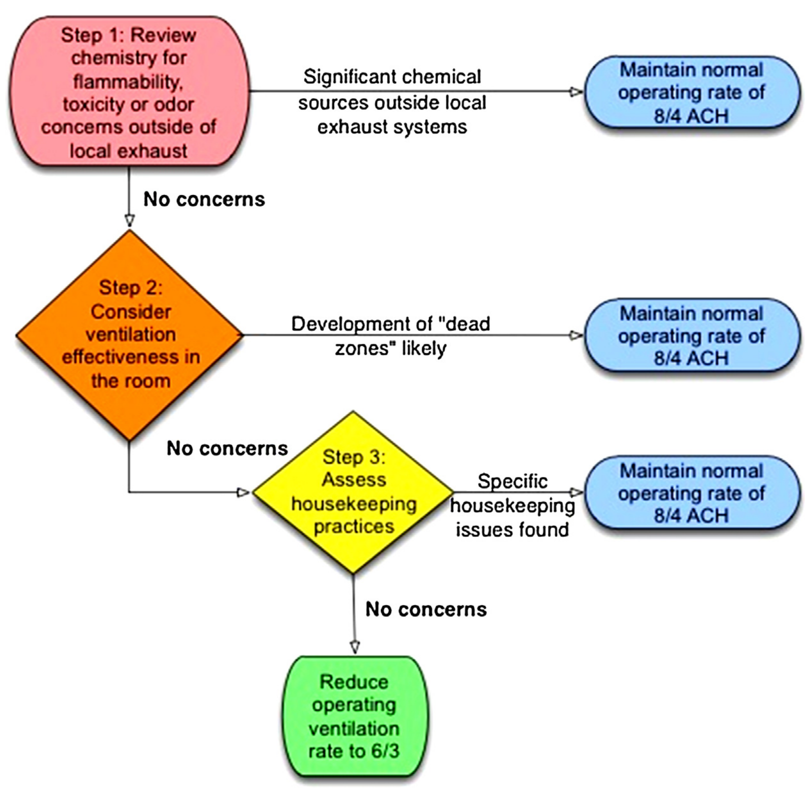

Figure 1. Decision logic for assignment of operating ventilation rate in air changes per hour (occupied/unoccupied).

managed by the same suite of controls. The control banding strategy was developed by industrial hygienists in the biosafety, pharmaceutical, and nanotechnology settings to identify control methods appropriate for situations in which hazard information is limited, or the hazards of concern change regularly.[3–7] Because the chemical laboratory shares similar risk assessment challenges with these settings, we believe that using control bands for assigning laboratory ventilation rates is appropriate.

The control bands we describe below are based on experience at Cornell with computational fluid dynamics and field assessment of ventilation effectiveness with tracer gases, such as carbon dioxide. Based on this work, we believe that laboratory ventilation can be an effective control strategy at flow rates of 6 air changes per hour (ACH) during occupied periods and 3 air changes per hour during unoccupied periods when there are no significant sources of volatile chemicals outside local ventilation devices and if the general ventilation design and housekeeping permits effective air movement through the space. In other cases, 8 air changes per hour are necessary to control chemical vapors adequately. It is important to remember that these are the minimum flow rates to be delivered by the building's control system to control chemical hazards; in many labs, higher ventilation rates may be necessary due to makeup air requirements for laboratory chemical hoods, to maintain temperature or humidity control, or based on human or animal occupancy of the space.

Because there are a variety of codes and standards that apply to both ventilation practices and chemical hazards, it is necessary to use professional judgment to balance the various considerations they represent. In addition to the identities of the chemicals used in the laboratory, factors such as the quantity, concentration and toxicity of the chemicals used; the type of equipment they are used in; the availability of local exhaust in appropriate areas; and the effectiveness of the ventilation in the room should be considered in making this risk assessment. For this reason, assignments of a particular laboratory room or ventilation control zone to a control band must be based on the professional judgment of a qualified person who has visited the site.

A "qualified person" is someone who is familiar with a variety of chemical processes; understands laboratory hazards and safety practices; has experience with assessing these hazards and practices in a variety of laboratories; and can assess the significance of ventilation effectiveness factors present in specific laboratory settings. We have found that in some situations, studies of ventilation effectiveness of existing systems are necessary to complete this assessment. This should also include identification of specific indicators, such as odors or health symptoms, which indicate the laboratory is under-ventilated, as well as a projected date for a reassessment based on how quickly the chemical processes being used are changing. These considerations are key elements of our "management of change" strategy within the LVMP.

THE GENERAL VENTILATION CONTROL BANDS

The general ventilation control banding system used here identifies four ventilation control bands, but uses two as the mainstays of our Laboratory Ventilation Management Program. These are outlined in Figure 2.

THE CHEMICAL CONSIDERATIONS

Normal Ventilation

Laboratories in which there are significant volatile chemical or specific process hazards for which employee exposures are to be controlled by the general ventilation system are designated for ventilation at 8 ACH when the laboratories are occupied and 4 ACH when the labs are unoccupied. These are the normal operating rates established for the University.

Specific chemical classes that require this level of ventilation are those used in concentrations and quantities sufficient to create significant inhalation or flammability hazards. In general, chemicals which have the "Danger" signal word in the Globally Harmonized System (GHS) based on their volatility and for which dilution is an acceptable control strategy should be considered for this control band. These chemicals have GHS H-codes associated with flammability and toxicity concerns.[8,9]

This recommendation relies on the expectation that significant point sources are contained by effective local exhaust. This can be in the form of a laboratory chemical hood, local point exhaust, or an appropriate chemical storage cabinet. The general ventilation patterns are such that they may not prevent areas of chemical accumulation near emission sources not controlled by local exhaust. Laboratory workers must be trained in and follow best practices for using ventilation systems in the laboratory; principally the proper use of the laboratory chemical hood and the building control system provided in their laboratory. They should also be competent in determining which processes should be located in a hood based on risk criteria.

Moderate Ventilation

In many cases, where the use of volatile chemicals are limited or used solely in the laboratory chemical hood, the specified ventilation rates can be lowered to 6 ACH occupied and 3 ACH unoccupied. In these cases, worker education about laboratory ventilation can be more generic and simplified. Specific chemical classes that require this level of ventilation are those that are used in concentrations and quantities that can create odors and nuisances. These chemicals generally have the "Warning" signal word in the GHS system based on their volatility; specifically these chemicals have GHS H-codes associated with respiratory irritation. In these rooms, the general ventilation patterns are expected to prevent areas of chemical accumulation.

Low Ventilation

In the lowest hazard control band are laboratories where the chemicals used are minimal and ventilation requirements can be lowered to those required to support exhaust devices in the

General Ventilation Control Band	Default Minimum General Ventilation Rate	Drivers for this Recommendation	Examples
Normal ventilation	8 ACH occupied / 4 ACH unoccupied	High intensity laboratory chemical use; especially use of chemicals with H224, H225, H226, H304, H330, H331, H332 GHS Physical and Health Hazard codes	Classroom labs with multiple bench top sources of the same chemical; or labs with poor distribution of ventilation in the space
Moderate ventilation	6 ACH occupied / 3 ACH unoccupied	Volatile or toxic chemical use with H334 and H335 GHS Health Hazard codes that are restricted to local exhaust areas; no significant sources on bench top	Laboratories with chemical use outside hoods limited to instrumentation, small bench top operations, or closed systems
Low ventilation	Less than "moderate" rates, determined by review of operations in lab	Instrument labs and other spaces with intermittent sources that require once through ventilation, but have no significant chemical sources with GHS ratings	Machine shops without solvent use, storage areas of non-volatile chemicals
Lab-specific ventilation	Determined by specific review of non-chemical hazards in labs	Based on biosafety considerations; make up air concerns; temperature concerns; high hazard chemicals such as H220, H221;	BSL 3 laboratories; hood-driven labs; labs with high heat producing equipment

Figure 2. General ventilation control bands.

space, temperature, and human occupancy needs for the room. It should be noted that such rooms may have other ventilation needs, such as significant heat sources which may drive ventilation needs. One potential strategy is to manage occasional or discrete chemical risks with local exhaust ventilation rather than general ventilation. For example, provision of portable exhaust systems with HEPA and/or carbon filters could potentially allow reduction of general ventilation rate in these situations. The ACGIH's *Industrial Ventilation* manual can be consulted for information about the design criteria of such systems.[2]

Depending on the contaminants expected to be used in a low ventilation room, air exhausted may or may not be of an appropriate quality to be returned to occupied spaces. Determinations in this regard should be made on a case by case basis and include chemical spill scenarios when these determinations are made. In any case, chemical use is not the driving factor in ventilation rates, so there is no generic ventilation rate associated with this band; rather a specific engineering review based on the actual use of the room is required. Chemicals appropriate for use in rooms with this level of ventilation are those that have no hazard designations in the GHS system based on their volatility or are used in concentrations or quantities that create no significant volatility hazard. Laboratory-related situations that may allow a lower level of air exchanges that require specific review include temperature control rooms, classroom laboratories outside well-defined occupancy periods, and storage rooms for non-volatile chemicals.

Specific Ventilation Design Required

Some specific laboratory uses of chemicals may require higher or lower ventilation rates than those generically described above due to specific hazards or requirements that arise from the processes conducted in the laboratory. Assignment of ventilation requirements for these situations lies outside the scope of the generic control banding process and requires specific analysis to determine ventilation needs. Such analysis should be documented with a "basis of operation" report outlining the considerations used in defining the ventilation parameters. This analysis should be supported by development of specific training programs to assure that laboratory workers understand the assumptions and operation of the laboratory ventilation system.

NON-CHEMICAL CONSIDERATIONS IN ESTABLISHING VENTILATION RATES

A variety of non-chemical factors can impact final ventilation recommendations for a specific laboratory. These include:

- the size of the laboratory relative to the make-up air demands of local exhaust ventilation in the lab (laboratory chemical hoods and exhaust points);
- open lab designs with multiple ventilation zones or high ceilings with diffusers that may not effectively ventilate the entire laboratory;
- the presence of heat generating equipment in the space; or
- special occupancy considerations for the laboratory (e.g., classroom laboratories with a large number of students conducting simultaneous work with small amounts of chemicals).

Evaluating these factors often require consultation with both the facility's operating engineers and occupants to be sure that everyone impacted by the ventilation rate understands the basis for the EHS recommendation. Specific impacts of these factors include:

1. In all cases, ventilation recommendations based on chemical use are minimum flow rates which are overridden by make-up air, temperature and occupancy considerations. That is, if more air is required to maintain necessary supply air for local exhaust in the lab, maintain negative pressure in the lab, control temperature, or maintain recommended fresh air levels for the number of people in the room than is required for managing chemical concentrations in the lab, the higher flow rate should be used. Note also that this system is designed to address normal laboratory conditions; if ventilation is considered part of the emergency response system of the laboratory, provisions for other levels of ventilation may be necessary.
2. This analysis is based on situations where laboratory operations exist within a single ventilation control zone. In situations where a variety of laboratories co-exist within a ventilation zone, the most conservative ventilation band must be applied to the whole zone.
3. Another important factor to be considered during the field assessment for assignment of control bands is the distribution of air supply and exhaust points in the laboratories. It may be more effective to reconfigure ventilation, by replacing or relocating supply and exhaust diffusers, to increase its effectiveness than to increase the air flow in the lab. Such a determination will require specific study of air flow patterns in the laboratory in question.

The Control Banding assessments may also identify other changes in the ventilation operations that would enable them to operate more efficiently. Decommissioning laboratory chemical hoods, changing temperature set points, adding fan coils for less energy intensive cooling, or redefining ventilation control zones are some of these methods. These ideas should be documented and reviewed with affected stakeholders as they arise.

The final step in the assessment process includes observations of laboratory chemical management practices and housekeeping. When there are excess items stored that generate fugitive emissions or there is a general lack of control of operations there is the risk of unnoticed spills or reactions due to incompatibility issues. In these spaces, the assessment should include looking for poor storage of chemicals and bottles with broken or decayed caps. Such labs may also lack proper training and conscientious oversight of where chemicals are used on a routine basis. In such cases, the ventilation rates can potentially be reduced following training which leads to a change in lab practices.

SUSTAINING THE CONTROL BANDING SYSTEM

Sustained use of this control banding system is a key element in the success of the Laboratory Ventilation Management Plan. The risk assessment process should be designed so that it can be understood by laboratory stakeholders, with the support of the qualified person designated by the LVMP. Optimally, these reviews should occur at the beginning of each academic term to accommodate changes in laboratory activities.

The assessment form we have developed to provide guidance for collecting information during field visits can be found on the Cornell Environmental Health and Safety website at: http://tinyurl.com/cu-vent-cb.

In about 80% of spaces where we have completed such assessments we have determined that the reduced airflow rates are appropriate for the space. However, the other 20% of spaces have been found in a variety of departments and in unpredictable locations. The reasons for maintaining the higher airflow rates in these labs include:

- Volatile or toxic chemicals are used in locations that would allow for significant exposures if they become airborne;
- The design of the lab is such that there are areas with inadequate airflow in certain locations at the moderate room exchange rate;
- There are boxes, furniture or equipment in the room located in such a way that they block proper distribution of the ventilation flow; or
- There is poor storage and management of chemicals indicating a lack of training in the hazards associated with the chemicals in the space

While the control banding system described here is a key part of the larger LVMP, other policy elements of the LVMP are necessary to support safe and healthy laboratory work that is environmentally sustainable. These include:

- On-going training programs for the various stakeholders about the safety value of the laboratory ventilation and proper use of a laboratory chemical hood;
- A system for tracking the impact of any changes in the laboratory ventilation rates, both in regards to laboratory air quality as well as energy and maintenance costs for the ventilation system, and the costs of implementing the LVMP;
- Design criteria for new and renovated laboratories on the campus; and
- Operation and maintenance procedures for the ventilation equipment serving the laboratory spaces. This includes the periodic testing and inspection of the fume hood and continuous commissioning of ventilation control systems. Effective use of these efforts requires a good working relationship between the LVMP designated qualified individual and the facility operators.

In addition to these policies and procedures, other key elements of the LVMP are an ongoing roster of the laboratory ventilation equipment and an associated data archive of its operating history. Over time, this information will support efforts to ensure that the ventilation system meets the overall goal of providing a safe, healthy and sustainable workspace for laboratory staff and support personnel.

CONCLUSION

Ventilation is a fundamental health and safety protection strategy in the laboratory. The ventilation system's effectiveness is integral to controlling airborne chemical contaminants while maintaining an environment that can support a wide variety of laboratory processes involving hazardous materials. Managing energy intensive ventilation systems and incorporating sustainable energy considerations into their design and operation is important for monitoring the effectiveness of laboratory ventilation as a safety measure. Accomplishing this goal requires application of professional judgment of qualified individuals who understand the hazards associated with chemical processes in the laboratory and the factors that impact the effectiveness of the laboratory's ventilation system. Such judgments benefit from the use of an overall strategy to improve consistency and repeatability of the assessment results.

Control bands provide a strategy for better understanding how the laboratory general ventilation system fits into the overall safety management system used in academic laboratories. It is important to remember that laboratory ventilation and other engineering controls are only part of the complete strategy to protect laboratory workers and support staff from chemical hazards. Identifying less hazardous chemicals to use; providing training and oversight of workers; and appropriate use of personal protective equipment are all equally important parts of the laboratory safety program.

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