Chemical Fume Hood and Laboratory Ventilation:
Operation, Design and Performance Testing

2013

Consensus Statements

Outcomes of Fume Hood Summit

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Introduction

This report describes the outcomes of the 2013 Fume Hood Summit held at the University of California, Los Angeles (UCLA). The purpose of this meeting was to review and update a group of consensus statements generated during the 1998 Workshop on Chemical Fume Hoods sponsored by the Howard Hughes Medical Institute[1]. Experts from the field of laboratory ventilation, including several participants from the previous workshop, came together to generate a new set of consensus statements that reflect the changes in laboratory chemical ventilation technology and use over the last 15 years. The summit focused on the same four broad topics of discussion that the previous workshop established:

1) Selection, Use, and Operation of Laboratory Chemical Fume Hoods
2) Hood and Laboratory Design
3) General Laboratory Ventilation System Design
4) Hood Performance Testing

Participants were divided into four groups prior to the summit; each group was responsible for preliminary review of and updates to the old consensus statements, creating entirely new statements if necessary.

In this report, we present revised and newly formulated consensus statements to encourage additional discussion on laboratory ventilation and invite stakeholders to share information on successful ways to reduce overall energy use without compromising health and safety of the occupants and their surrounding environment. Stakeholders include laboratory workers, laboratory facility operators, laboratory designers and environmental health and safety staff. Various parts of this report may be of more interest to one or more of these groups.

Major Changes in laboratory ventilation in the last 15 years

The major changes in laboratory ventilation design and operation in the last 15 years include:

- Increased use of building-wide variable air volume systems in laboratories with chemical fume hoods.
- Heightened awareness of the impact of laboratory ventilation systems on financial and environmental sustainability of laboratories, and energy conservation.
- Advances in laboratory chemical fume hood design that allow for effective containment at lower face velocities and flow rates.
- Changes in the American National Standards Institute (ANSI) Z9.5-2012[2] and National Fire Protection Association (NFPA) 45 standards[3], which replace the specific minimum flow requirement of 25 cfm per square foot of work surface through all chemical fume hoods with a more flexible case by case assessment. The updated standards provide some guidance on how to select the minimum flow requirement and suggest in most cases the minimum to be between 10 and 25 cfm per square foot.

- Advances in laboratory chemical fume hood containment testing allowing for more accurate assessment of containment under various ventilation conditions.
- Vastly improved tools such as software for overall laboratory ventilation system design and operation, e.g., the Computational Fluid Dynamics (CFD) software, building controls automation systems, and real-time sensors to monitor air contaminants.
- Improvements in the design, operation and testing of ductless hoods as an alternative to standard laboratory hood exhaust for some lower hazard material handling.
- Improved design of supply and exhaust systems to achieve effective air change patterns with reduced room air change rates.
- Impact of sustainability initiatives, which have gained increased importance at many universities and research institutions. For example, UCLA sponsored a chemical fume hood competition in fall 2008 to examine how much energy could be conserved by lowering sash heights of chemical fume hoods. A reduction of the average sash height of 5.4 inches resulted in a reduction of 1.4 million lbs. of CO_2 emissions in one year – the equivalent of taking 205 cars off the road for an entire year.

Consensus Statement Development Process

This report was developed by consultation among 18 participants of the Fume Hood Summit. All have demonstrated experience in fields related to chemical fume hoods and laboratory ventilation. Several experts represent professional or trade organizations and are directly involved in laboratory ventilation system design and testing. Other experts include Environmental Health and Safety (EH&S) professionals from academic institutions, who oversee laboratory ventilation in their respective facilities. It should be acknowledged that laboratory workers or building operators were not included in the discussions.

Prior to the workshop all participants were asked to complete a survey providing their opinions on the 31, previously published consensus statements[1]. They were asked which of these statements were still valid, and which required reassessment given the advances in fume hood design and laboratory ventilation in the past 15 years. The pre-workshop evaluations helped to focus the workshop to areas, the group believed had undergone significant changes in the past 15 years. To prepare for the workshop, participants were divided into 4 groups to review the consensus statements from each of the broad topics outlined above. Participants were placed in groups according to their areas of expertise or interest. Each group created a presentation summarizing their suggestions for the revisions to the old consensus statements, including any new information used to inform their discussion.

During the first day of the summit, each group presented the proposition to their revised statement to the other participants and led a discussion to garner feedback. After each topic was thoroughly discussed, the individual groups further revised the statement based on the discussion outcome. At this time, it was recorded whether all group members were in consensus about the validitv of the statements; for some of the statements no consensus was achieved. Any necessary additional revisions to the statements were collected at this time. Due to time limitations, groups finalized their consensus statements after the summit.

Findings

The original 31 consensus statements have grown to 55 statements. Of these, 32 encompass new statements or statements with major revisions of the earlier versions; they are labeled with “new”. Twenty-three of the original statements still hold the consensus of the groups in that their content is valid, even 15 years later; these statements are labeled with “reaffirmation”. Due to time constrains, 10 of the original statements could not be addressed in this workshop; they are listed in Appendix A and will require more in-debt research. An overview of all discussed statements is provided in Appendix B.

The statements are grouped by the 4 main categories listed above. Each statement is followed by a descriptive or supporting documentation. With 24 statements, the “Hood Design” topic had the largest number of statements, followed by “System Design” with 17, “Performance Testing” with 8 and “Selection, Use and Operation” with 6 statements. **Two statements (34 and 35) were not supported unanimously; eleven experts agreed to the statements and 7 disagreed. One statement (25) had 1 dissenting opinion. These statements are followed by the opinions of those who differed with the statement.**

Consensus Statements:

1. Selection, Use, and Operation of Laboratory Chemical Fume Hoods

Overview statement on Selection of Laboratory Chemical Hoods and their Face Velocity

Correct selection and use of a laboratory chemical fume hood will depend on the hazards associated with the work done in the hood. The primary purpose of a laboratory chemical fume hood is to contain, dilute, and exhaust volatile chemicals arising from a chemical process. Other types of hoods may be necessary to address other types of hazards; these are discussed below.
When information about the work to be done is not available, reasonable predictions for such work must be made in a prudent way to assure that the hood can be expected to perform as needed. When work in the hood changes, hood operating practices may need to be adjusted, with the advice of the qualified individual named in the institutional Laboratory Ventilation Management Plan. See ANSI Z9.5 for discussion of qualified individuals[2]*. Effective containment of hazardous materials in the hood can be achieved at a variety of face velocities, depending on the design of the hood, its location relative to general air patterns in the laboratory, and the way it is used. Containment for a specific hood installation must be verified by field testing. A variety of criteria have been proposed for satisfactory containment testing; these are addressed elsewhere in this report.*

Consensus 1 (Reaffirmation with updates-old consensus 28)
No single face velocity can be designated for all hoods to assure containment of airborne chemicals in the hood. Manufacturer recommendations can provide guidance for design of ventilation systems which include laboratory chemical hoods, but on-site evaluation of the factors named above by a qualified individual can result in adjusting the face velocity to ensure the researcher safety and sustainability of the science being conducted.

Key issues of concern for selection of the proper face velocity to maintain containment in laboratory chemical hoods include:

- Hood design (for example, the depth of the hood, provision of airfoils, etc.);
- Air flow patterns in the hood, particularly as impacted by equipment in the hood;
- Location of the chemical process in the hood;
- User practices;
- Ventilation system control logic based on sash height and occupancy sensors; and
- Air turbulence in the laboratory in the area of the hood.

The consequences of an incorrect face velocity include:
Too high:

- Unnecessary energy use;
- Degraded containment due to turbulence within the hood entrance and the hood itself;
- User disruption in terms of comfort, increased evaporation of volatile chemicals, interference with operation of equipment in the hood, and other impacts;
- Noisy operation of the hood and make-up ventilation system; and
- A misleading feeling that higher face velocities provide better containment

Too low:

- Loss of containment, particularly near the face of the hood;
- Accumulation of vapors in the hood work area; and
- Release of a flammable solvent resulting in significant flammable vapor concentrations inside the hood or ductwork.

These potential consequences of an imprudent face velocity should be considered in establishing a target face velocity and tolerance for variation from that target as well as training of users about warning signs of poor hood containment.

Consensus 2 (new)
The minimum volumetric flow rate for a laboratory chemical hood shall be based on a hazard analysis of a maximum credible scenario of the chemicals to be used in the hood when the sash is at its minimum height.

In addition to containment, airflow rates in the hood should be reviewed to assure that accumulation of flammable chemicals in the hood does not occur. No single volumetric flow rate will assure that all chemical processes in the hood proceed as expected without over-ventilating the hood. Understanding the hazards of the chemicals to be used in the hood, their generation rate, the location of emission sources in the hood, and the hood dilution factor are necessary to establish a specific flow rate requirement for this consideration. See ANSI Z9.5

section 3.3.2 and its references[2] and Klein *et al.*[4] for further information about conducting such hazard assessments. If this information is not available during the design process, conservative rates of between 150 to 375 ACH (Air Change per Hour) in the hood (around 10 cfm/square foot and 25 cfm /square foot in a 6 foot hood) can be used, depending on the type of chemistry expected to be conducted in the hood. Other considerations, such as minimum general ventilation for the lab as a whole, may override this minimum hood flow consideration.

Consensus 3 (new)
Fire suppression systems should not be required in all laboratory hoods.

There are concerns that such systems may require significant maintenance, present concerns about interactions between the suppressant agent and chemicals in the hood, and the potential for disruption of the hood function. Neither the International Fire Code Section 5.10 nor NFPA 45 requires such systems in laboratory hoods. However, the review of intended chemical fume hood operations should address the risk of fire, and provisions for automatic suppression provided as appropriate. Several systems can be readily retrofitted to existing installations.

Consensus 4 (reaffirmation-old consensus 12)
The use of alternative local ventilation systems in place of laboratory chemical hoods requires specialized risk assessment to support the design of the chemical process and training of users in the unusual hazards associated with their work and operation of their exhaust systems.

Laboratory hoods are designed to address a variety of hazards in different ways. Selection of the appropriate hood for the hazard of concern requires clear understanding of both the hazard and the ventilation equipment. These options are well described in *Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards*[5]*.*

Consensus 5 (new)
The use of any non-volatile, particulate hazardous materials in the hood risks contaminating the hood structure and ventilation system as the materials move through the ventilation system.

Hood users must take responsibility to assure that such uses are documented to support decontamination of these components. In case of a hood with unknown contamination, the process described by ANSI/AIHA Z9.11-2008 Laboratory Decommissioning should be followed[6].

Consensus 6 (reaffirmation—old consensus 20)
All chemical laboratory hoods must meet the same minimum containment criteria.

This includes those marketed as “high performance”, low velocity and ductless hoods.

2. Hood and Laboratory Design

Considerations to Alternative Hood Uses and Designs

As an alternative to the traditional laboratory chemical hood described above, new designs have been developed to address novel hazards or save energy. Examples of these include "ductless chemical fume hoods" and HEPA filtered stations for work with nano- and biological materials.

Considerations to System Design

Laboratory chemical hoods operate in the context of a larger building wide laboratory ventilation system and their effectiveness depends on their effective integration into that system. Many hood design parameters are impacted by the capabilities of the building's ventilation control system as a whole (for example, the presence of occupancy sensors in laboratories or the ability to change the exhaust rate from the hood depending on the sash height).

Consensus 7 (new)
If the operating concept for a lab includes temporarily taking hoods out of service for repairs, maintenance, or decommissioning, administrative procedures are needed to designate, approve and confirm each such transition, and prominent, clear indication that a hood is out of service must be provided.

Chemical processes in the hoods must be made safe before such actions are finalized and the chemical fume hood declared as safe for subsequent activities, including potential decommissioning and disposal.

Consensus 8 (reaffirmation with expanded discussion—old consensus 14)
If there is any interactive adjustment that enables the hood user to alter the baffles, flow rate, or face velocity of the hood other than moving the sash, the user needs explicit training on the purpose and effect of the adjustment.

For example, the user needs to understand how and when to use the emergency flow setting. Other manual flow adjustments should be prohibited for untrained personnel.

Consensus 9 (new)
If a special process or substance warrants altered air flow rates, hood users need to know which hoods support the operation, and how to start and end the special flow setting.

Hoods designed for these situations should be considered a non-standard laboratory chemical hood and be treated similarly to those described in Statements 4-6.

Consensus 10 (new)
Within the range of usable flow rates and velocities established by the considerations in Statements 1 and 2, chemical fume hood flow rates may be dynamically adjusted to satisfy room air balance requirements. This means that exhaust flow through a hood can be used as part of the overall room level exhaust.

Considerations on Proper Laboratory Hood Use

Because of the many possible designs and operating parameters of a chemical hood, proper use of a laboratory chemical fume hood requires both education of the user in general laboratory safety principles and specific training in the use of the hood they are using. This education and training will support the proper use of the hood to protect the user and the chemical processes occurring in the hood. In addition, we describe specific common concerns that have been found in laboratory hood use and the reason for these concerns.

Consensus 11 (Reaffirmation—old consensus 3)
General laboratory chemical hood education for laboratory workers is necessary and shall be provided in an effective manner initially and repeated if processes change or as necessary as a refresher.

Many hood users will use a variety of hoods in the course of their work; therefore, general education of laboratory workers about hood containment principles is required. Specific topics to be covered in such an educational program include:

- The types of common laboratory chemical fume hoods and the hazards they are intended to manage
- How to match the hazards of a laboratory process with the appropriate local ventilation device
- Signs and consequences of poor hood operation
- The impact of sash opening area on hood containment
- Interpretation of hood monitors and alarms
- Common control system protocols and their impact on lab ventilation as a safety process
- Hood and ventilation system maintenance requirements
- Resources available for more detailed information about laboratory ventilation design and use materials

Consensus 12 (new)
Individual hoods must be labeled with instructions specific to that hood describing how it is controlled and how to respond to alarms generated by the hood.

Simple instructions about the operation of specific hoods are necessary because of the wide variation in control and alarm schemes found within most institutions. Alarms may be related to lowered face velocity; position of the hood sash; and higher than expected energy use and the proper response to these signals must be identified.

Consensus 13 (reaffirmation—old consensus 12)
Laboratory chemical fume hoods are not designed for chemical storage.

Storage of chemicals or chemical waste in the hood should be discouraged because it creates the opportunity for increased risk in case of an unexpected event in the hood and because unused objects left inside a chemical fume hood can contribute to poor airflow distribution and ultimately affect containment. Chemical storage cabinets in the vicinity of the hood can be exhausted through the ductwork of the hood when requirements of applicable fire codes are followed.

Consensus 14 (reaffirmation—old consensus 7)
Laboratory chemical fume hoods can provide some protection from flying particles, but are not explicitly designed for blast resistance.

The sash may provide some containment of flying particles and splash protection, but should not be expected to withstand an explosive reaction or control movement of airborne particles. Both vertical and horizontal sashes can provide this type of protection.

Consensus 15 (new)
Operations that are larger than laboratory scale as described by OSHA's lab standard or which involve non-volatile, particular hazards may require specially designed ventilation enclosures and need more specialized training for the users.

Examples of such uses include quantities of chemicals larger than 20 liters, use of small quantities of highly hazard chemicals such as explosive compounds, dispersible nanoparticles or operations that generate particulates. Normal laboratory scale amounts of aerosols can be effectively contained by laboratory chemical fume hoods. Biological aerosols can be effectively controlled in biological safety cabinets. Nanomaterials may need special consideration to ensure excessive loss of material and containment to prevent release to the environment.

Consensus 16 (reaffirmation—old consensus 5)
Training in general laboratory ventilation principles shall be provided for all facility maintenance and operations staff relative to their duties.

Personnel who perform maintenance on laboratory ventilation systems are better equipped to perform this task if they have a good understanding of how the system works to protect people and what they can do to help maintain good protection.

Emerging Challenges

Consensus 17 (reaffirmation—old consensus 29)
Ongoing research and development of information about hood performance should be shared among laboratory organizations and support staff to continue to improve our understanding of hood performance.

Organizations that currently publish such information include the International Institute for Sustainable Laboratories, the Division of Chemical Health and Safety of the American Chemical Society, American Society of Heating, Refrigeration and Air Conditioning Engineers, and the American Industrial Hygiene Association. A central clearinghouse should be established.

Consensus 18 (new)
Ongoing development of a laboratory specific hazard assessment process for assigning processes to appropriate hoods is a pressing need.

A model hazard assessment protocol that helps to determine when local ventilation is required to manage the hazards of a chemical process would support improved use of laboratory hoods. Such analysis should address fire and toxicity concerns associated with such work. Recommendations by the Globally Harmonized System[7] and the American Chemical Society[8] about this issue provide helpful direction in this effort.

Consensus 19 (new)
Further research into human factor issues associated with hood ergonomic and alarm systems should be conducted to improve their usability.

Laboratory chemical hoods present many ergonomic challenges for users. Examples of such issues include the variety of operating procedures and alarms associated with different style hoods and sashes, the challenge of a single working height and distance for a variety of users and operations, confusion about the appropriate use of the hoods relative to other local ventilation devices, and the use of hoods by people unable to stand. User education and training programs should address these challenges, but research to support best practices in these programs is needed. Ergonomic challenges may be more problematic with the deeper hoods.

Consensus 20 (new)
Control of hazardous engineered nanoparticles in the laboratory environment is an emerging issue to be addressed by improved hazard analysis and control strategies. See statement number 15.

General Laboratory Chemical Hood and Laboratory Design Challenges

Consensus 21 (new)

Dilution ventilation airflow sometimes referred to as general ventilation, and measured in terms of the laboratory air change rate, combines with the system's ventilation effectiveness and the quantity of fugitive emissions, to determine the airborne concentrations of chemicals within the occupied laboratory environment. Dilution ventilation alone will not control the background level of laboratory room air contaminants.

These three factors (dilution ventilation, system effectiveness and fugitive emissions) are the primary influences on the level of background or average contaminant concentrations in a laboratory room environment. Due to variation in these factors, there is no single air change rate that can be specified for all cases. Furthermore, air change rate alone does not provide adequate protection for laboratory occupants for many processes conducted in laboratories. For this reason, other protective strategies, such as reduction of chemical loads, use of local ventilation systems, training and oversight of laboratory staff and use of personal protective equipment, must be considered as part of the protection system when hazardous chemicals are used in laboratories.

Consensus 22 (new)

Long term exposure to fugitive emissions gone undetected and unmitigated should be considered as a potential toxicity hazard. The role of dilution ventilation as a means to control the buildup of fugitive emissions and odors in the laboratory, as well as help to control the impact of spills should be considered as part of the risk assessment supporting the safe use of hazardous chemicals in a laboratory.

Fugitive emissions released into a laboratory room environment that are not detected and purged or at least purged through sufficient levels of dilution ventilation can create a buildup of background levels of contaminants that can potentially create hazardous long term levels of exposure. Dilution ventilation can also be used to control concentrations of air contaminants from smaller level spills and help clear the contamination from larger spills (more than 500 ml) faster. However, for larger spills, no amount of dilution ventilation can prevent personal exposures and evacuating the laboratory is the only safe response.

Consensus 23 (new)

Dilution ventilation is not an effective control approach for sources of chemical and particulate contaminants less than approximately one meter (-3 feet) from a worker. Dilution ventilation will only be effective in reducing the personal exposures of operators further from the source due to its contribution to the control of background contaminant concentrations.

When an operator must work close to chemical or particulate contaminant sources on a bench, a chemical fume hood or other local containment should be provided.

Consensus 24 (new)

The only effective control approach to prevent short term personal exposures of operators working outside a laboratory chemical fume hood in the immediate vicinity (under 1 meter) of bench top sources of chemical and particulate contaminants are local containment devices such as canopy hoods or snorkels.

If bench top contaminant sources cannot be controlled or eliminated, then local containment, such as a canopy hood or snorkel, is the only effective control approach to minimize or prevent personal exposures of contaminants used outside of a chemical fume hood. This containment will also reduce background contaminant concentrations and reduce personal exposures of operators who are located farther from the source.

Consensus 26 (new)

The effective air change, not the calculated air change rate, determines the decay rate of contaminants in the laboratory space.

There is not always recognition that the effective air change, not the calculated air change rate, determines the decay rate of contaminants in the laboratory space. Effective and calculated air change rates may differ by a substantial amount due to the impact of diffuser locations, stratification effects, short circuiting and other factors. This is particularly true in facilities designed before the advent of computational fluid dynamic models allowed design of laboratory spaces with this concern in mind. In addition, effective rates are not uniform throughout the laboratory. If the objective is increased ventilation rates, changing the air supply diffuser location and type relative to equipment and potential release locations may increase the ventilation effectiveness and provide faster purge rates for a given rate of dilution ventilation airflow.

For consistency, the volume used in the calculation of air change rates should include total room heights up to the ceiling deck or a dropped ceiling if such exists and not consider furniture and equipment. Specification of the air change rate should also include whether it is an exhaust or supply airflow rate. In general, it is preferable to use total exhaust airflow to calculate air change rates.

Consensus 27 (new)

The lab room airflow rate is determined by the highest of the sum of the exhaust device makeup air requirements such as hoods, biosafety cabinets (if connected to the facility's exhaust system) and snorkels, the room's thermal load airflow requirements, and by the dilution ventilation airflow requirements.

The above three factors influence the actual room airflow at any given time based on the instantaneous levels of these three requirements. The room flow offset also is a factor here but typically doesn't change.

Consensus 28 (new)

For labs where energy efficiency is important and thermal loads may be high, it can be valuable to decouple the supply airflow rate from the cooling requirements by using local water cooling approaches.

For lab rooms where the cooling load will often become the highest airflow requirement it can be more energy efficient to use local room cooling solutions such as chilled beams, fan coil units, VRV (Variable Refrigerant Volume cooling units), or other local cooling solutions to augment cooling instead of using supply air for all of the cooling requirements. Note that this is only true if the cooling load often requires higher airflows than the exhaust and dilution ventilation airflow requirements.

Consensus 29 (reaffirmation—old consensus 15)

A prescriptive air exchange rate (air changes per hour) cannot be specified that will meet all conditions in a laboratory room.

The appropriate ventilation rate for clearing a room of fugitive emissions or spills varies significantly based on the amount of release, chemical evaporation rate, level of chemical hazard, room configuration, and ventilation system effectiveness. There remains no correlation between air change rates and personal exposure to chemicals in laboratories.

Consensus 30 (new)

A risk assessment involving the lab room and its operation, use, and materials should be conducted periodically to assess appropriate means to ensure the health and safety of the lab room occupants.

Both for new facilities and periodically as the function, operation, and use of a lab room changes, a risk assessment should be carried out by a qualified health and safety professional to determine the appropriate means to ensure the health and safety of the lab room occupants. This may include assessing whether the laboratory has adequate local exhaust devices, chemical fume hoods, dilution ventilation, and other contaminant control devices as well as if the operators and occupants have proper training to ensure that the laboratory will be operated in a safe and effective manner.

Consensus 31 (new)

Traditional laboratory dilution ventilation airflow rates can be modified as laboratory room conditions change if a management system is in place which can reliably identify changes in experimental procedures and materials.

Fixed minimum airflow rates between 6 and 12 air changes per hour (ACH) have been used in the past as the basis for designing laboratory ventilation systems. However, recent research demonstrated that volatilized contaminants resulting from a defined spill cleared most significantly when the ACH was increased from 6 to 8, but only diminished in clearance when the ACH was further increased to twelve[9]. While the study questions the usefulness of very high

ACH rates, at least for the indicated types of spills, it is clear that ventilation rates at the very low end of the traditional range may not be appropriate for all laboratories. With this in mind, minimum ventilation rates should be established on a room-by-room basis (if enabled by the building control system) considering the hazard level of chemicals expected to be used in the room, the procedures to be performed in the room, the scenarios being controlled by the dilution ventilation system, and the effectiveness of the ventilation system in moving air in all parts of the room. A reliable process for facilities and/or EH&S staff to identify and react to changes in lab chemical processes should be described in a lab ventilation management plan (LVMP)[2].

Consensus 32 (new)
Automated control of ventilation rates can be a prudent alternative to constant general ventilation rates in lab settings.

Within the constraints described in 31, changing ventilation rates with automated controls (e.g. occupied/unoccupied control via occupancy sensors or time schedules, or else demand based control using gas and particle sensing technologies) may be a prudent option to save energy. For this reason, operational flexibility in the equipment controlling the ventilation rates in a lab is an important design feature. As the operation, materials, and or hazard level of a room change, the operational range of the minimum ventilation rate should be evaluated as well as the technology being used to vary the ventilation rate. Sensing technology must be appropriate for anticipated conditions and maintained on a regular basis. The ability of the institution to recognize and implement such changes should be considered when selecting design ventilation parameters and equipment.

Consensus 33 (new)
A risk assessment should be conducted for any lab where a reduction in dilution ventilation rates may be implemented through either an occupied/unoccupied strategy or a demand based control strategy.

This assessment should be conducted by qualified Environmental Health and Safety professionals in partnership with facilities staff who understand the operations of the building's ventilation system and identify the hazards of concern, the scenarios for which control of ventilation is expected to be appropriate, and the change management strategies for the review of the assessment.

3. General Laboratory Ventilation System Design

Consensus 36 (reaffirmation—old consensus 10)
The location of the laboratory chemical hoods is an important consideration in achieving optimal performance.

There is now more guidance on this topic, such as types and location of diffusers, proximity of multiple hoods, and use of CFD (Computational Fluid Dynamics), in such references as DiBerardinis[10] and NIH Guidelines on HVAC design considerations[11].

Consensus 37 (reaffirmation—old consensus 16)

Manifolding of laboratory chemical hoods is acceptable and common practice, where appropriate, and can provide advantages for both safety and energy conservation.

Manifolding chemical fume hoods to more than one exhaust fan has a number of advantages for both health and safety and energy conservation and is a practice encouraged by various standards. The institution and contracted design team should consider the advantages of this design approach, including consideration of means to accommodate near term and future research applications for which manifolding is not an acceptable practice. Advantages of manifolded systems, (multiple hoods connected to one or more exhaust fans in lieu of individual fans connected to single chemical fume hoods) include:

- Continuity of exhaust when an individual fan exhaust fails due to mechanical failure. (Note: this is an advantage only when two or more fans are used to service the manifolded chemical fume hoods. If a single fan is used to service multiple hoods, a single fan, single hood arrangement would actually provide a lower overall risk associated with mechanical fan failure).
- Additional dilution and discharge above the discharge point due to additional mass from the manifolded system. This reduces the concern for rooftop worker exposures and re-entrainment of exhausted air via introduction at air intakes
- Easier provisions of emergency power to all exhaust fans. A manifolded system can employ two or three exhaust fans. Two fans can be set to run under emergency power. This reduced emergency exhaust load puts less of a strain on the exhaust system which may not have supply fans equipped to run on emergency power. Single hood-to-fan systems would require emergency power to each fan and a significant building negative pressure when operating under emergency power (which can inhibit the ability to readily operate egress doors) or increase provision of emergency power to supply fans relative to that necessary for a manifolded system.
- Energy conservation is more readily accomplished with a manifolded system. Since it is highly unlikely that all chemical fume hoods on a manifolded system will be used at the same time, the system may be sized or set to run at a reduced flow compared the total exhaust load for a single fan to hood system (system diversity factor).

Code limitations on the ability of the designer to utilize manifolded systems for hazardous exhaust systems (International Mechanical Code – Section 510), are exempted for laboratory systems in recognition of the low concentrations in duct systems for laboratory operations provided the following criteria apply[11]:

Manifolded systems may not be used unless all the following criteria are met:

- All of the ductwork and other connected laboratory exhaust devices within the occupied space and shafts are under negative pressure while in operation.

- The ductwork that is manifolded together within the occupied space originates within the same fire area.
- Each control branch has a flow regulating device.
- Perchloric acid hoods and their connected exhaust are not manifolded.
- Connected radioisotope hoods are equipped with filtration and/or carbon beds.
- Connected biological safety cabinets are filtered.
- Continuous static pressure can be maintained in the ductwork (emergency power). This requirement has been modified in the IMC (effective 2015) to include the requirement for redundant fans with capability to independently provide necessary exhaust and will operate when the primary fan goes down.

Recent changes to the International Mechanical Code (effective in the 2015 IMC)[12] allow for hazardous exhaust ductwork originating in different fire areas to be manifolded together in an unoccupied common shaft if meeting the provisions of section 717.5.3, exemption 1.1 of the International Fire Code. This change reduces the space needed for the installation of a manifolded laboratory ventilation system while still maintaining safety.

Consensus 38 (reaffirmation—old consensus 17)

a) Recirculation of exhaust air from laboratory chemical hoods and local exhaust hoods shall not occur.

b) Recirculation of room air from a laboratory to the same laboratory is acceptable practice if based upon an exposure risk assessment.

c) Recirculation of room air from a laboratory to surrounding spaces is generally not acceptable practice. An exception could be possible if the stringent provisions of ANSI Z9.5 – 2012, section 5.4.7.1 are met.

Exhaust air from laboratory hoods and other special local exhaust systems shall not be recirculated. The design of these ventilation systems is not for the treatment of chemicals that are captured or otherwise contained within the hood and ventilation system. NFPA 45 specifically prohibits the recirculation of air from such systems when flammable chemicals are in use and ANSI/ASSE Z9.5 states that exhaust air from laboratory hoods shall not be recirculated to other areas[2,3]. However, hoods designed to treat the captured air and return the air to the same laboratory work area are accepted practice if design selection is based upon a hazard assessment of the work activity as stated in the ANSI/ASSE Z9.7 standard. In addition, the requirements of ANSI/ASSE Z9.5 must be followed where recirculation can only be done to the same work area when hood operators have control of the hood work practices and can monitor the status of air cleaning. Examples of these containment devices include ductless chemical hoods, type II biological safety cabinets, and certain glove boxes.

ANSI/ASSE Z9.7 provides guidance on the hazard assessment and analysis requirements to avoid the potential for recirculating contaminated air. ANSI/ASSE Z9.5 also sets criteria for recirculating general room exhaust from a laboratory to other areas. Recirculation of room air within a laboratory for temperature and humidity control (internal air handlers such as fan coil units or ventilated chilled beams) is acceptable when the risk of unsafe concentrations is minimal. However, recirculation of room air from a laboratory to another space where the occupants do not have control of the laboratory work activity or can monitor the status of air cleaning is generally not acceptable practice.

Consensus 39 (reaffirmation—old consensus 18)
Designing for system flexibility is advantageous.

The ability to design for system flexibility provides an opportunity to adapt the system to meet the changing needs of dynamic laboratories. Many new labs have the capability to fairly easily reconfigure casework, utility feeds and other lab equipment services. Providing a lab ventilation system that can adapt exhaust and chemical fume hood location/configuration as well as change make-up air needs is advantageous. For example, the relocation or change of researchers and their equipment, processes and needs may not require a large renovation in some cases (especially where the lab is relatively new or newly renovated). The ability to accommodate changes without major renovation of the ventilation systems can reduce disruption of laboratory activities and minimize needs to significantly change maintenance procedures. However, designing with flexibility as a goal can incur additional costs. Performing a life cycle cost analysis of the laboratory ventilation system over its expected life can provide owners with information on these costs and benefits.

Consensus 40 (reaffirmation—old consensus 18)
Designing with diversity is an acceptable practice but it must be done with care.

Designing for diversity differs from designing for flexibility. Systems designed for diversity may limit flexibility because they have only enough capacity to operate a predetermined percentage of laboratory chemical fume hoods at any one time. Both value engineering and sustainability can drive designs to 'right' size fans, ducting, air handlers and associated equipment. Thorough life cycle analysis can help highlight the aspects of these affected by designs (i.e. there is a sustainability cost to a more significant renovation or the need for new space because of limitations on a programmed space). One aspect of designing for flexibility in new labs may include balancing the goals of flexibility, sustainability and cost. Other aspects of designing for flexibility relate more specifically to installation details, equipment, and ductwork and chase layout that may allow for closer to 'plug and play' access for changes to exhaust ventilation systems. More research is needed to determine appropriate diversity for different types of research labs.

Consensus 41 (new)
Performing a life cycle cost analysis of the laboratory ventilation system over its expected life will provide information to optimize good design decision making.

Consensus 42 (reaffirmation—old consensus 21)

Either variable air volume ventilation (VAV) systems or constant air volume (CAV) ventilation systems can provide for safe operation of laboratory chemical hoods.

Both CAV and VAV systems can regulate exhaust flow from the laboratory chemical hood. There is no inherent advantage of one system over another regarding hood performance. Both have advantages and disadvantages and the decision of which one to use will depend on the individual circumstances. VAV systems offer significant benefits in energy saving by reducing flow when the laboratory chemical hood is not in use or is in use with a small opening area. Reduced flow specifications should be carefully determined to assure safe operations for all in-use conditions. VAV systems can offer more flexibility than CAV systems. However, they are more difficult to design and they require complex and expensive control systems as well as sophisticated commissioning protocols and maintenance procedures.

Performance of a laboratory chemical hood depends on many factors. One factor common to all laboratory chemical hoods is the need to regulate the volume of air exhausted from the hood. The exhaust flow must be of sufficient magnitude to provide adequate containment over the range of usable sash configurations. The exhaust flow also must be stable to minimize turbulence with in the laboratory chemical hood.

VAV systems are the most commonly used systems in laboratory buildings with a higher density of chemical fume hoods. Some of the advantages of the VAV chemical fume hood exhaust systems are as follows:

- They reduce energy utilization by varying the air volume with respect to demands and by facilitating the installation of centralized heating and cooling energy recovery.
- They reduce the number of exhaust fans. By combining hoods in a central system, one can often reduce the need to one or two large central fans. This can also apply to CAV systems with some effort.
- Because the total number of hoods in use at any time is estimated to be anywhere from 30 to 80%, the central mechanical systems can be reduced in size for a cost savings provided adequate warning systems are in place to indicate when the maximum allowable hood use has been exceeded.
- In a small laboratory with a large number of chemical fume hoods, but not all of which are used at all times, a VAV system may allow reduction of makeup air supplies in the laboratory.
- Systems can be made more flexible for future hood installations.

The disadvantages of a VAV system are as follows:

- Operation of VAV systems requires active researcher participation to achieve potential airflow and energy reductions by closing hood sashes when they are not loading or working in a hood. If the sashes are not modulated, the airflow and heating/cooling savings will not be realized.
- Increased preventive maintenance and calibration is required on VAV systems.

- Higher first cost for controls/controlled devices are the norm.

Some advantages of both CAV and VAV manifold exhaust systems are as follows:

- One or more central fans can be installed as a backup to provide continuous ventilation in the event of a fan failure. In this manner, some ventilation is guaranteed to all chemical fume hoods at all times. If one installs a single fan to a chemical fume hood, there will be no ventilation in that chemical fume hood if the fan fails.
- As the number of chemical fume hood stacks is minimized, those remaining can, with less expense, be increased in height to reduce the possibility of reentry of exhaust contaminants into the building. Also, the effective stack height is increased as the mass of the exhaust increases.
- If a bypass damper is provided at the inlet side of exhaust fans on the roof, the air exhausted can be diluted, thereby minimizing the chemical concentration of air exhausted.
- As more chemical fume hoods are connected, the concentration of a particular chemical will be diluted.
- Reducing the number of individual stacks increases usable floor space and reduces the need for shafts.

Items that might be considered disadvantages to both CAV and VAV systems are as follows:

- Mixing incompatible chemicals in the exhaust stream may result in an unsafe situation. This is highly unlikely for most research laboratories given the relatively low concentrations of materials in most exhaust streams, but nonetheless should be considered. It should be noted that unusually hazardous or toxic exhaust streams might require a separate exhaust system because of special requirements for filtration, duct materials, and/or fire or explosion protection (e.g., radioactivity, perchloric acid).
- When the control equipment used is a hot-wire anemometer element in the exhaust stream, it may be hazardous with certain chemicals being exhausted. Additionally, the element may become corroded and nonfunctional.

Consensus 43 (new)

All relevant codes and standards shall be reviewed for applicability and implemented as required. This will support the design, installation and maintenance of a safe and efficient laboratory ventilation system.

The institution wishing to design a new laboratory exhaust system or modifying an existing system needs to be knowledgeable regarding both existing and proposed changes to the codes and standards which apply in its jurisdiction. This knowledge can help prevent design approaches which violate local regulation or may enable the design team to include desirable approaches otherwise thought to be prohibitive. The end goal of the design is a system which is safe, effective, and efficient.

Various codes and standards apply to laboratory ventilation systems. It is the responsibility of the institution owner to identify those which address laboratory ventilation and adhere to those which are applicable. These codes and standards, when properly applied, can serve as the underpinning for safe and proper lab ventilation system design. It is important to realize that standards are primarily voluntary for implementation, while codes such as the International Codes are mandatory when adopted by your state[2,3,13,14]. ANSI and ASHRAE standards, such as ANSI Z9.5, ANSI Z9.7, NFPA 45, and ASHRAE 62.1 are voluntary standards, unless referenced by an adopted code or statute in your state or local jurisdiction. It is important to have someone on staff or on retainer at your institution who is familiar with applicable codes and desirable standards for reference for building or renovation projects involving laboratory exhaust systems. Where standards, or sections of standards, contain information which is vital to the proper design and operation of laboratory ventilation systems, these standards should be incorporated into your institution's design and construction guidelines since they may not be referenced by state or local codes.

The International Mechanical Code (IMC)[12], has been adopted or in use in 46 states. The pertinent section of the IMC for laboratory ventilation is IMC 510. This section was modified in 2001-2002 to provide language which is more relevant and appropriate for laboratory exhaust systems. IMC 514 addresses energy recovery systems as applied to hazardous exhaust.

Laboratory designers are challenged to meet design guidelines for both energy conservation and safety. The International Energy Conservation Code, adopted in 42 states, provides requirements for energy conservation which may also be supplemented by state statutes. ASHRAE 90-1 and 189.1 also address energy conservation as applied to mechanical ventilation systems.

IMC 510 defines a hazardous exhaust system as one where, in the absence of ventilation and under normal operating conditions, contaminant concentration could be either above 25% of the LEL (Lower Exposure Limit), or where 1% of the LC50 (Median Lethal Concentration) could be exceeded. Once a system meets the criteria for design as a hazardous exhaust system, the design must follow the criteria provided in section 510, including but not limited to the requirement to maintain duct concentrations below 25% of the LEL. If this would be the case, the exhaust system is "hazardous exhaust" and the system would need to meet the design requirements of IMC 510. Presently, IMC 514 states that energy recovery ventilation systems shall not be used in hazardous exhaust systems covered in section 510. Recognizing that this code language is overly restrictive and prohibits sensible energy recovery methods for hazardous exhaust systems, section 514 was recently modified (effective for IMC 2015) to allow for recovery of sensible heat only, utilizing coil type heat exchangers (run around loop) on hazardous exhaust. Enthalpy wheels and fixed plate heat exchangers would still not be allowed. With regard to recirculation of hazardous exhaust to other areas, IMC 510 currently contains the following language: "Contaminated air shall not be recirculated to occupiable areas. Air containing explosive or flammable vapors, fumes, or dusts; flammable, highly toxic or toxic gases; or radioactive material shall be considered to be contaminated." Based on concern that this language implies that hazardous exhaust can be recirculated if somehow cleaned, this language has been removed from IMC 510, (also effective for IMC 2015) to clarify that exhaust from a hazardous exhaust system is not to be recirculated to other areas. Various standards, including ANSI Z9.5, ANSI Z9.7, and ASHRAE 62.1 contain language which set circumstances and parameters which must be met for recirculated exhaust air.

Institutions familiar with relevant mandatory and non-mandatory code and standards content can reference this material in their site design and construction guidelines as previously stated. One can also propose early adoption if approved, but not yet effective, IMC code language into their state mechanical codes or can request application of the new content in a present building project from their local authority having jurisdiction (AHJ) and an "alternative means and methods" to achieve desired results.

Consensus 44 (new)

Reliable management of change procedures are necessary to ensure lab ventilation systems are, and continue to be, appropriate for the research conducted.

At the planning stage, laboratory design elements, equipment, and operational assumptions, must be weighed against the potential and scope of possible changing laboratory conditions. Where design elements, equipment, or operating conditions may need to be modified due to changing lab conditions, the ability for that change to be recognized by those who would need to take action must be evaluated. The consequences of unrecognized change and subsequent lack of the associated modification should be considered. Where unacceptable risk (e.g. low reliability of recognition and/or reaction to changes in key safety parameters) is concluded, a modification in initial design assumptions or equipment would be warranted.

Various applications and approaches to reduce energy expenditures associated with laboratory exhaust have been developed. These approaches include, but are not limited to, low flow hoods, hoods with filtration which return air back into the lab space, demand controlled ventilation which minimizes air exhaust rates based on fixed contaminant monitoring points, and a control banding approach to laboratory ventilation where lab air exchange rates are associated with the type of research conducted in the laboratory.

One of the challenges for those who are responsible for achieving the proper balance of safety and energy conservation in their research laboratories is determining the conditions where a measure may be appropriate and where it may not, in other words, the operational bounds of the design approach. Where safe design bounds exist (e.g. an approach which may be appropriate for low hazard material but not for higher hazard materials), the institution needs to determine whether initial design conditions are expected to be reliably constant or if not, what would need to be done if initial conditions change and whether the change will be noted by those who must take action. This concept of proper management of changing conditions is a key element of OSHA's process safety management standard and is known as "management of change".

Consensus 45 (reaffirmation—old consensus 19)
Risk assessment and subsequent lab design shall consider all sources of lab contaminant generation, not only chemical fume hoods, so that point of use exhaust ventilation can be utilized to the maximum extent possible.

For chemical intensive laboratories, the contribution to the inhalation exposure of laboratory personnel from fugitive bench top emissions can meet or exceed the exposure contribution of leakage from poorly performing chemical fume hoods[15].

While proper design of chemical fume hoods, proper commissioning, and proper maintenance are important for reducing employee exposure, all sources where contaminants are generated should be examined closely to determine if enclosure and/or point of use exhaust ventilation can be utilized to further control exposures. In cases where a smaller enclosure or point of use ventilation can be used to replace a chemical fume hood, reduced exhaust volumes and associated energy savings can be realized.

Consensus 46 (new)
Laboratory users, with assistance from EH&S, when planning and conducting their research, should select lower hazard materials and reduce emissions to the environment where feasible and consistent with the research mission.

Use of lower hazard chemicals can reduce the risk to lab personnel and perhaps result in a lessened need for exhaust ventilation and associated energy consumption. Reduced emissions from the chemical fume hood to the exhaust system translate to reduced emissions from the exhaust stack.

The concept of waste minimization, typically defined as the effort to reduce the amount of solid and liquid wastes generated in a laboratory, could and should also be applied to the gases, vapors, and particulate which are emitted from laboratory exhaust stacks. This application of green chemistry includes, among other considerations, the selection of least hazardous materials and, where appropriate, hood scrubbers or other reaction devices to reduce emissions.

Consensus 47 (new)
Exhaust stack design is a critical component of a safe and effective laboratory ventilation system.

Efforts must be taken to ensure that re-entrainment from exhaust stack discharge locations and mechanical equipment support areas is minimized to help protect maintenance staff and building occupants from contaminants.

Design of a laboratory exhaust system should be approached from a "cradle-to-grave" perspective. Proper location of exhaust stacks with respect to air intakes, as well as the volume and velocity of the air released from the stack, have an effect on both maintenance worker exposures and the potential for re-entrainment of laboratory contaminants. Design considerations downstream of the hood and upstream of the exhaust stack include, but are not limited to, consideration of proper transport velocities, materials of construction, joints, and avoiding positive pressure in the duct in occupied areas. References such as the ACGIH Industrial Ventilation: A Manual of Recommended Practice for Design[16], and ANSI Z9.5[2] provide guidance on proper exhaust stack design to provide rain protection without obstructing the point of discharge from the duct.

4. Hood Performance Testing

Consensus 48 (new)

a) **VAV speed of flow response shall be measured during "as installed" commissioning tests to verify that the response time meets the design specifications and does not negatively impact hood containment.**
b) **It is prudent to measure VAV response time during routine evaluations of hood operation to verify that the response time is consistent with results found during the commissioning tests.**

VAV chemical fume hood controls are intended to modulate flow in response to a change in sash position or operating mode. The time required for the VAV controls to modulate flow when opening the sash has been demonstrated to affect containment during ASHRAE 110[17] sash movement effect (SME), tracer gas containment tests. The ASHRAE 110 standard contains two methods to measure speed of response where flow can be recorded directly from the VAV flow terminal or the velocity in the bottom slot of the chemical fume hood baffle can be measured using a hot-wire anemometer where the slot velocity is directly proportional to the flow through the chemical fume hood. Measurement of VAV response time is necessary to help characterize operation of the chemical fume hood and ensure proper operation of the VAV controls.

Consensus 49 (new)

It is important to assess the stability of flow as an indicator of VAV operation, but the allowable variance and means to calculate variance requires further study and definition.

VAV chemical fume hood control systems modulate flow depending on the position of the chemical fume hood sash and/or operating mode. The ability of the controls to maintain a relatively constant flow or minimize fluctuations in flow at a fixed sash position or operating mode has been demonstrated to impact hood containment and room air balance. The same techniques used to measure VAV speed of response are employed to collect data to evaluate the stability of flow or fluctuations in flow during the test period.

Consensus 50 (new)

A more prescriptive method and means to conduct airflow visualization challenge tests beyond that described in the ASHRAE 110 standard would provide more comparable and

meaningful results. Conducting an airflow visualization challenge test by itself does not alleviate the need to conduct a tracer gas containment test.

Airflow visualization tests provide a good means to evaluate airflow patterns within a chemical fume hood and qualitatively assess hood containment. However, the methods described in the ASHRAE 110 standard[17] are not sufficiently prescriptive to ensure chemical fume hood testers challenge the hood, evaluate and report the results in a consistent fashion. The airflow visualization smoke test described in the Public Works & Government Services of Canada (PWGSC) MD15128 Chemical Fume Hood Standard[18] should be considered for inclusion in the ASHRAE 110 standard. It may be possible to use smoke tests conducted in a consistent and prescribed fashion to identify potential for escape from a chemical fume hood and alleviate some of the factors affecting performance prior to conducting more expensive and time consuming tracer gas tests.

Consensus 51 (new)

a) **All unique chemical fume hood models (manufacturer, type, size, etc.) shall be tested "as manufactured" to evaluate hood design and all chemical fume hoods shall be tested "as installed" to evaluate the effects of the lab environment and operation of the ventilation systems on hood performance.** (reaffirmation—old consensus 25)
b) **Contract documents should include specifications and assign responsibility to address issues identified during chemical fume hood tests and demonstrate that the problems have been remediated through subsequent re-test.**
c) **The need to conduct "as used" tests to evaluate the impact of equipment and procedures conducted in the chemical fume hoods shall be decided by the lab owner.**

The ASHRAE 110 method indicates that tracer gas containment tests can be conducted to evaluate the chemical fume hood "as manufactured", "as installed" and "as used". There is not sufficient information available to prescribe "as used" test conditions that would provide a representative test of containment. Where appropriate and applicable, personal exposure monitoring should be used to evaluate "as used" hood performance.

Consensus 52 (reaffirmation—old consensus 30)

a) **It is prudent to develop appropriate test methods and conduct tests to evaluate performance of any ventilated exposure control device when installed and during routine assessments. Work is required to develop appropriate standard test methods for local exhaust ventilation used for exposure control. In the absence of a standard, the designer or manufacturer shall provide a test method and operating specifications.**
   The designer/manufacturer of the devices shall state a level of performance and conduct "as manufactured" tests to define recommended operating specifications to meet the defined level of performance.

Chemical fume hoods and biological safety cabinets are subject to performance tests typically during commissioning and routine assessments. However, other devices often used to control contaminants and prevent overexposure in the lab such as canopy hoods, spot exhaust (snorkels), ventilated balance enclosures, slotted hoods, downdraft tables, etc. are typically not subject to performance tests and very little guidance exists to conduct meaningful tests. Performance criteria should be based on the level of protection required or desired function (i.e. containment, capture, exposure level). Operating specifications include how the ECD should operate to provide the required performance (i.e. flow, velocity, pressure or other relevant parameters).

In the absence of information from the original designer or manufacturer, the owner is responsible for providing the performance criteria and operating specifications. References such as the ACGIH Ventilation Manual or literature for other similar hood types can be consulted to develop appropriate criteria and specifications.

Consensus 53 (reaffirmation—old consensus 13)
The performance of the laboratory chemical hood generally improves as the area of the work opening decreases.

Consensus 54 (reaffirmation—old consensus 22)
Current performance tests do not reflect in-use exposure.

Consensus 55 (reaffirmation—old consensus 23)
Predicting exposures was not the reason the ASHRAE Standard 110 performance tests were developed.

Disputed Consensus Statements

Consensus 25 (reaffirmation—old consensus 11)
Directional airflow controlled by flow offsets and airflow tracking, rather than the use of pressure differentials, is typically a more successful approach for the design of ventilation systems for laboratories to assure negative pressurization of laboratory spaces.

Airflow direction is used in laboratories to provide a secondary barrier to control the spread of contaminants to other areas. In laboratories other than cleanrooms, the contaminants contained by the secondary barrier are chemicals that are not removed by direct exhaust equipment, such as chemical fume hoods. By maintaining a negative pressure in a laboratory room, any chemicals that are accidentally released are generally contained in the room in which they were released and do not readily spread to surrounding areas.

The general theory of room pressurization control is to maintain a differential between the supply and exhaust airflow quantities, to either pressurize or depressurize the room relative to the adjacent spaces to ensure that air flows from the cleanest to the dirtiest spaces. The exception to this rule is the “clean room” environment which has special requirements to meet the intent of this statement. In an actively controlled system, the actual relative room pressure can be monitored using a differential pressure sensor and the supply or exhaust airflow quantities adjusted to maintain the desired set point. However, direct pressure control is sensitive to disturbances such as the opening of doors and infiltration. Tight envelope construction is required to maintain proper pressure differential. System control may become unstable if doors are opened frequently or left open.

Alternately, under the general principal of flow tracking control, the supply and exhaust airflow quantities are monitored and controlled to maintain a set differential between the supply and exhaust volume. The differential can be adjusted to obtain the desired differential pressure. To ensure flow tracking works accurately, all supply and exhaust airflows must be accurately monitored. This method does not recognize nor is it affected by the impact of opening of doors or infiltration.

When a large opening is created such as by an open door, thermal effects caused by different temperatures at the top and bottom of a door may occur and thus will not guarantee directional airflow, which can be important depending on the use of the laboratory. Pressure differential control may increase the room offset in these situations but usually not by enough to guarantee directional airflow. If room containment is critically important then air locks or other positive containment methods are needed. A hazard assessment must be performed to determine the extent of the criticality of maintaining directional airflow at all times.

For those rooms that are literally sealed environments with extremely low leakage required, room differential control is typically preferred over flow offset control due to the very low offsets that are needed. However a hybrid approach may also be advantageously used in this situation where the room differential measurements reset the offset set point of a flow offset control system.

Dissenting Opinion

Ralph Stuart:
*"For **25**, I'm still concerned that it is important to be clear that pressure differential considerations in BSL-3 labs do not necessarily follow the logic described for clean rooms (because aerosols act differently than chemicals), so I would like to have that comment memorialized in the final report."*

Consensus 34 (new)
If lower unoccupied dilution ventilation rates are desired for saving energy in a given lab room then this approach shall only be considered once qualified Environmental Health and Safety professionals have determined as part of their risk assessment that a lower unoccupied ventilation rate is appropriate for the given lab room. Some examples of the criteria or considerations that might be used to permit the use of a lower unoccupied flow rate would consist of the following:
(1) access to the lab room is prevented both during unoccupied dilution ventilation rate periods as well as for at least one hour or more after the higher occupied ventilation rate has been reengaged to properly flush the space of contaminant buildup;

(2) all chemicals or any material that could constitute a hazard have either been removed from the lab or placed in an operating fume hood or storage cabinet, as well as any active operation or process that could possibly release hazardous material into the lab room has been shut down during the unoccupied period, or
(3) an active sensing system is being used in the lab to detect the presence of lab airflow contaminants and provide a higher purge or occupied dilution ventilation airflow level to prevent the buildup and presence of lab room contaminants.

When a lab is unoccupied, as indicated by time clock or room occupancy sensors, some lab owners have indicated a desire to use a reduced unoccupied minimum ventilation rate that can reduce the total airflow to the space for these periods provided the hood exhaust and thermal demands are also reduced. However, the use of a lower unoccupied minimum ventilation rate can carry with it some restrictions that may limit or reduce its application in many laboratories. As such this approach may save significant amounts of energy but designers and facility operators must apply it carefully after consulting with the responsible Environmental Health and Safety professionals.

The reason for these possible limitations is that dilution ventilation is a means to control the release and buildup of fugitive emissions. In many cases fugitive emissions, which may be released by open or poorly capped bottles, leaking gas cylinders, etc. can be released and buildup during unoccupied periods. Even though occupied dilution ventilation rates may be reengaged when occupants enter the lab room, it often takes at least an hour for the lab room to be flushed out to eliminate the buildup of these fugitive emissions as shown for example by several research papers[9]. Since this design concept should maintain low, safe concentrations of contaminants in the air at all times, it is not part of this concept to allow increased contaminant concentrations on the grounds that the workers are absent. For example some of the conditions that could preclude use of this concept would be lab spaces where there is a possibility of fugitive emissions during unoccupied times, the use of chemicals stored outside the hood that may leak into the space, the operation of research experiments and chemically related operations during unoccupied times or other operations that might release chemical vapors or particulates into the lab space that could increase or build up when air change rates are reduced.

If on the other hand concentrations of air contaminants could build up during unoccupied times then the use of lower unoccupied airflow rates might still be used but only if for example access into the lab room can be absolutely restricted and prevented during both the unoccupied period and additionally for at least an hour more after the occupied lab ventilation rates have been reengaged. Note however that this approach may be difficult or not feasible to implement in some lab facilities, and should only be approved after review and a formal risk assessment by a qualified health and safety professional of these specific concerns regarding unoccupied contaminant concentrations and operator access.

Alternatively, a lower unoccupied airflow rate can be used if an active air contaminant sensing and control approach such as demand based control is used in the lab room that can reliably detect contaminants of concern and increase room ventilation rates on demand to prevent a buildup of unsafe concentrations of air contaminants in the lab even during unoccupied times. Finally, a lower unoccupied airflow rate may be also used based on meeting another set of criteria that is determined by the responsible Environmental Health and Safety professionals and implemented as part of their risk assessment.

Consensus 35 (new)

Demand based control or the active 24/7 sensing of lab room air contaminants provides opportunities for potentially significant energy conservation and may identify situations where source control and or local containment measures can better control lab room contaminants as well as provide higher purge airflow rates. A risk assessment is also recommended for rooms where this concept is implemented to ensure its use will be appropriate.

Active sensing of air quality in individual laboratories also sometimes known as Demand Based Control (DBC) or Centralized Demand Control Ventilation (CDCV) is an approach that can potentially provide significant energy conservation and can help with lab safety. For example, it can provide information about lab safety conditions, which can be used to educate laboratory occupants about the impact of their lab operations on the environmental quality of the lab. With this approach, the minimum airflow rate is varied based on sensing the laboratory's actual air quality level or "air cleanliness." Primary contaminants in general laboratories include chemical, particulate, and aerosol contaminants, and appropriate sensors are necessary to detect the contaminants in each space. For special purpose labs in particular that have a dominant potential contaminant, the sensors should be evaluated for their ability to detect that contaminant. Carbon dioxide measurements are also often recommended for occupancy related ventilation requirements, particularly where higher people density can occur such as in teaching labs.

When air contaminants are sensed in the laboratory above a given threshold, the minimum air change rate is increased proportionally to an appropriate level to purge the room. This purge level depends on the system and airflow control device capabilities but is typically recommended to be in the range of 8 to 16 ACH. When the air is "clean" and contaminants are below the previously mentioned threshold, then this approach can safely reduce lab air change rates to as low as 2 ACH, so the energy savings from this approach can be very significant.

It should be noted that these systems cannot be used in BL3 or BL4 biological containment spaces for a variety of reasons. It also bears repeating that these systems should not be used as exposure monitoring or toxic gas or vapor alarm systems. Note that spaces with very high hood densities, such as more than two 6' hoods per 250 sq. ft. lab module, are not good applications for this approach since the airflow rates are typically dominated by the minimum required fume hood flows even when the sashes are closed. Additionally these systems require periodic sensor calibration, maintenance, and monitoring of the system to ensure that the system is working properly and the application is still appropriate for use.

Dissenting Opinions:

Jack Price:

*"I am somewhat uncomfortable with **statements 34 and 35**. It seems to be promoting the active sensing (ventilation on demand) approach for lowering the lab ACH while discouraging the other approaches. Many of our labs are low risk (e.g., teaching labs) and occupancy sensors/pre-programmed operation times (that have a local override) can be a very reasonable approach. Unless these consensus statements can be edited to be more generic statements then statement 33 should be sufficient and I vote no on 34 and 35."*

Pamela Greenley:

*"I cannot support this **statement #34** as written. #33 advices on risk assessment before air change rate reduction is undertaken and we should leave it at that for now since our knowledge base is not sufficient to be prescriptive in the manner that #34 advocates. Also the guidance is uneven and difficult to follow. It is overly prescriptive for occupancy sensors but gives no guidance on how labs with chemicals which the sensors cannot detect should be evaluated.*

*I can't support **#35**. It is too technology specific and again does not address the technology's short coming that for most R&D labs only a small percentage of the chemicals in use can be sensed."*

Michael Labosky:

*"Consensus **statement 34** - Although the final draft wording is improved from earlier versions, I do not agree fully with the concept that one of the three suggested scenarios described would be necessary for a competent EHS Professional to recommend setbacks. Only the very last sentence in the supporting text and not the actual consensus statement, mentions this possibility. Although labs will vary potentially widely, the focus on the idea that significant fugitive emissions are present in labs is not supported here with data. The concept of how long purge takes is referenced, but the need for delayed entry or early (one hour) anticipated system startup to 'purge' a space is also not supported by data either. If such labs exist where setback (not emergency, spill or upset conditions) causes 'unsafe' levels of contaminants from fugitive emissions, the consensus statement should clearly state – these labs should not be set back under any conditions and sources of emissions corrected.*

*Consensus **statement 35** – A consensus statement highlighting demand control ventilation is not necessary in this document. The specific concern about this statement is that it includes the idea that lowering minimum ventilation rates in an occupied research laboratory based on periodic measurements made by sensing systems measuring 'air cleanliness' is an accepted EHS principle. There are some caveats described, but not enough of the information needed and system limitations are described. Although a later statement clarifies DCV sensing systems should not be used as exposure monitoring or toxic gas or vapor alarm systems (safety systems), I do not agree with a general principle of relying on 'air cleanliness' to determine occupied minimum ventilation rates for labs given the regular lack of complete information of* *chemical/material inventories, knowledge of materials in use and changing conditions of use in a research laboratory."*

Ken Kretchman:
*"Comment **34** - I believe the basic statement and supporting information as written imply that active sensing is the most feasible solution to a problem that is depicted in a way that I think is a bit misleading and not easily corrected with simple edits.*

*Comment **35**. - I have a concern about "can better control lab contaminants" in the statement and am not sure why there is a statement dedicated to this approach.*

Both preceding comments 32 and 33, particularly 32, acknowledge that DCV can be a prudent alternative.

As suggested by some of the summit attendees, I think statements 34 and 35 should be removed."

Jim Coogan:
***Statements 34 and 35** should be cut from the Fume Hood Summit Results. They detract from the document and will reflect badly on the group that produced it.*

This is not a new issue, popping up at the last minute. Members of the group discussed and re-worked this section of the document for some time. They made valuable progress. Statements 32 and 33 are succinct, accurate, realistic and even-handed. But statements 34 and 35 are still flawed in the 'final draft'. The document is much better without them.
Statements 34 and 35 discuss 2 ways to reduce ventilation in a lab room when the hazard is low and restore it when needed. We should describe those 2 methods from a similar point of view and in comparable terms. Instead, these statements are way out of balance. Specific examples of imbalance include:

- ***Need for EHS attention.** Statement 34 says the occupancy based approach "shall only be considered once qualified Environmental Health and Safety professionals" have assessed the risk. Statement 35 says "a risk assessment is also recommended for rooms where this concept is implemented." The tone is completely incongruous.*
- ***Uncertainty regarding hazards and operation.** Statement 34 mentions "all chemicals or any material that could constitute a hazard" and "any active operation or process that could possibly release hazardous material." It calls for a case where "access into the lab room can be absolutely restricted and prevented." Statement 35 describes "sensing the laboratory's actual air quality" in much more general and less absolute terms. It does not address the uncertainty involved in relating measurements to the risk of exposure.*

Further, Statement 34 calls for a one-hour delay between resuming the baseline flow rate and arrival of lab workers. This "requirement" has nothing to do with reality. Many labs run with unoccupied flow rates, but there might not be one that implements a delay between increased *flow and occupancy. The journal articles cited for support certainly do not endorse the proposed delay. "Clearance times" reported in the articles are not relevant to the transition between unoccupied and occupied conditions.*

Last, let me acknowledge my commercial interest in the issue. My employer delivers all kinds of lab ventilation control systems: constant volume, variable with fixed minimum, occupancy based setback and DCV. We succeed when our customers (lab users, facility managers, safety officers and HVAC engineers) are well informed about their options and choose approaches that fit their needs. We don't want them mislead. If published, statements 34 and 35 will certainly be used commercially to promote one approach and discredit the other.

Acknowledgement

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Appendix A

Original statements from the 1998 Fume Hood Summit not discussed during the 2013 Fume Hood Summit.

Expanded explanations of the statements can be found in DiBeradinis et al.[1]

Consensus 1
A laboratory chemical hood is a partial containment enclosure that vents to the atmosphere and protects workers by (1) minimizing the escape of chemicals generated within the enclosure, and (2) diluting contaminants to ensure concentrations remain below explosion limits.

Consensus 2
The requirements of the laboratory chemical hood user and the installation and certification requirements of the institution are essential considerations in the selection of the appropriate laboratory chemical hood.

Consensus 4
Training of users in the correct use of the laboratory chemical hood is essential.

Consensus 6
There is a need to develop a mechanism to collect and exchange data on the selection, application, and operation of laboratory chemical hoods.

Consensus 8
More research is necessary to determine if deeper laboratory chemical hoods are more effective than conventional laboratory chemical hoods.

Consensus 9
Present designs for laboratory chemical hoods may not be optimal. Future laboratory chemical hood designs should not be constrained by current concepts.

Consensus 24
The ASHRAE Standard 110 performance tests include the effects of the laboratory environment on laboratory chemical hood containment without reference to operational safety.

Consensus 26
Personal sampling programs should be used to measure actual exposures, particularly where there is high risk.

Consensus 27
There is a need for consensus for the meaning of numbers.

Consensus 31
There is a need for additional research to relate containment to exposure.

Reference

1 DiBerardinis, L. J. *et al.* Report of the Howard Hughes Medical Institute's workshop on the performance of laboratory chemical hoods. *AIHA journal : a journal for the science of occupational and environmental health and safety* **64**, 228-237 (2003).

Appendix B: Fume Hood Summit Overview of Statements Discussed

		Consensus			Topic						
Statement No.	Subject	Re-Affirm	Update	New	Hood Design	Laboratory Design	Ventilation System	Operating Specifications	Hood Use and Training	Lab Ventilation Management	Performance Testing
1	Face Velocity & Containment		X		X			X			X
2	Min. Exhaust Flow Based on Hazard Assessment			X	X			X	X	X	
3	Fire Suppression			X	X			X			
4	Alternative Local Ventilation	X			X						
5	Hood and Duct Contamination			X					X		
6	Standardize Fume Hood Performance	X						X			X
7	Notification for Out of Service			X						X	
8	Adjustment of Operation by Hood User		X					X	X	X	
9	Altering Flow for Special Applications			X				X	X	X	
10	Fume Hood Use as General Room Exhaust			X		X	X	X			
11	Laboratory Hood Training	X							X	X	
12	Hood Labels and Signs			X					X	X	
13	Chemical Storage in Fume Hoods	X							X	X	
14	Fume Hood Blast Resistance	X			X				X	X	
15	Larger Than Laboratory Scale Procedures			X					X	X	
16	Personnel Training	X							X	X	
17	Sharing of Information about Hood Performance	X								X	
18	Lab Hood Risk Analysis			X					X	X	
19	Hood Ergonomics			X	X						
20	Control of Nanomaterials			X	X				X	X	
21	Dilution and Ventilation Effectiveness			X		X				X	
22	Dilution Ventilation and Lab Ventilation Risk Analysis			X		X				X	
23	Dilution Ventilation			X		X				X	
24	Local Exhaust Ventilation			X	X				X	X	
25	Lab Pressurization	X				X		X		X	
26	Effective Air Change Rate			X		X				X	
27	Total Lab Airflow Rate			X		X		X			
28	Decoupling Supply Flow from Cooling			X		X					
29	Air Change Rates for Laboratories	X				X		X		X	
30	Lab Hazard Risk Assessment			X						X	
31	Variable Lab ACH			X		X		X		X	
32	Automated Control of Lab ACH			X		X		X		X	
33	Automated Reduction of Lab ACH			X		X		X		X	
34	Contaminant Sensing and Demand Control Ventilation			X		X		X		X	
35	Demand Control Ventilation for Energy			X		X		X		X	
36	Fume Hood Location	X				X				X	
37	Fume Hood Exhaust Manifolds	X					X			X	
38	Recirculation of Exhaust Air	X				X	X			X	
39	Design for Flexibility	X			X	X	X			X	
40	System Diversity	X					X			X	
41	Life Cycle Cost Analysis			X						X	
42	VAV and CAV Fume Hood Systems	X			X		X	X			
43	Follow Codes and Standards			X						X	
44	Management of Change			X							
45	Lab Ventilation Risk Assessment	X				X				X	
46	Hazard and Risk Reduction			X					X	X	
47	Exhaust Stack Design			X			X				
48	VAV Performance Tests			X			X	X			X
49	VAV Flow Stability			X			X	X			X
50	Airflow Visualization Tests			X							X
51	Fume Hood Testing Specifications		X					X		X	X
52	Local Exhaust Ventilation Testing Requirements		X					X		X	X
53	Fume Hood Containment and Sash Opening	X			X			X			X
54	Performance Tests versus Exposure	X								X	X
55	ASHRAE 110 Not intended to predict Exposure	X								X	X
	Count	19	4	32	11	18	9	21	14	39	10