TASK SHEET 1A

DETERMINATION OF LABORATORY AIRFLOW RATES

A Paper for the University of Washington written by:

Michael A. Ratcliff, Ph.D., P.E.
of
Rowan Williams Davies & Irwin, Inc.

RWDI
CONSULTING ENGINEERS
& SCIENTISTS

Thomas C. Smith, M.S.
of
Exposure Control Technologies, Inc.

ECT, Inc.

April 21, 2009

Introduction

Throughout the history of research laboratories, groups involved with design including management, architects, engineers, health and safety, trade organizations and regulators have been challenged by the issues of correctly determining basic design criteria and appropriate airflow specifications for laboratory ventilation systems. With laboratory design aimed at user safety, comfort, perception of a pleasing work environment, and recent trends towards sustaining energy efficiency, specification of these baseline criteria has become highly controversial. With laboratories operating at 100% outside air and at high air change rates, laboratories are known to be energy intensive compared to other buildings. Therefore, laboratory energy usage has come under scrutiny as energy policy and global warming receives increased nationwide attention. The article "Experimenting with Efficiency" [*Nature*, Nov 2007] summarizes the need and latest directions for reducing energy in laboratories.

A commonly discussed topic is the magnitude of air changes per hour (ACH) required to achieve a safe laboratory. Values for ACH have been recommended by various agencies including OSHA (4-12 ACH) and frequently discussed at conferences sponsored by the EPA/DOE Labs of the 21st Century (Labs21), AIHA and ASHRAE where the main themes are safety, energy conservation and green laboratories. Many papers have been authored or presented on the subject, including "Designing for Actual not Theoretical HVAC Requirements in Laboratory Facilities" [Carpenter, Labs 21, 2007] and "HVAC Design for Sustainable Labs" [Johnson, *ASHRAE* Journal, 2008]. One standard, the ANSI/AIHA Standard Z9.5 [AIHA, 2003] has recommended against using air change rates as a basis of design.

Air Change Rates and Inability to Provide Safety Through Ventilation Alone

The preponderance of information indicates that reliance on a single airflow rate or specification of an ACH for laboratory safety is imprudent and can lead to a false sense of safety. In reality, laboratory scale procedures with even modest emissions within the laboratory (not captured by an exhaust device) can result in odorous or hazardous concentrations that can exceed acceptable limits of concern (LOC) at any reasonable or recommended ACH.

RWDI has examined spills of a variety of liquid chemicals and found that most chemical spills need air change rates much higher than 10 ACH to meet occupational health limits within the laboratory room. Figure 1 below shows the percentage of liquid chemicals (out of 350 examined) that would meet their respective health limits and odor thresholds for a given room air change rate. Two spill sizes are shown, a large 500 mL spill and a small 5 mL spill. Uniform mixing within the room is assumed for the purposes of calculating average room concentration. However, local concentrations near the spill would be higher, which would make the required ACH higher for a given release.

The figure shows that 10 ACH would not meet health and odor limits for a large majority of chemicals with a 500 mL spill. Many chemicals would need over 100 ACH, which is not generally feasible. For even a minor 5 mL spill, 10 ACH would only meet limits for less than 60 percent of chemicals. This figure, with revisions, was presented at the Labs 21 conference. [Phillips, D.A., and Smith, A.L, Labs 21, 2006]

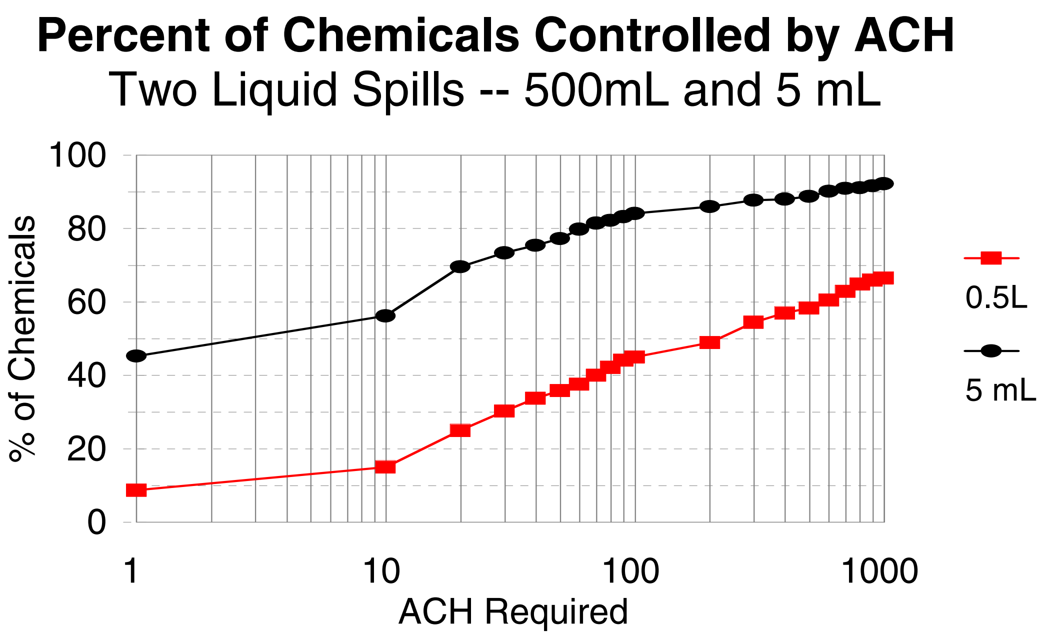

Figure 1. Percentage of Chemicals Controlled for Various ACH and spill sizes.

Likewise, ECT has also performed experiments and calculations of spills and gaseous leaks where near source concentrations can exceed a LOC at ACH historically specified or recommended for laboratories (up to 15 ACH). **Table 1** summarizes the calculations for 26 commonly used chemicals and several chemical generation rates. Typical chemical generation rates are listed in **Table 2**. **Table 1** shows that 10 ACH is not adequate for most chemicals and most generation rates. Only the values highlighted will meet LOC limits for 10 ACH or less.

Table 1. Required ACH assuming perfect mixing to limit concentrations of some lab chemicals to the maximum allowable concentration established by prevailing level of concern.

		Required ACH for Dilution to LOC					
Material	LOC PEL, TLV (PPM)	Gen. Rate = 0.1 lpm	Gen. Rate = 0.5 lpm	Gen. Rate = 1.0 lpm	Gen. Rate = 4 lpm	Gen. Rate = 8 lpm	Gen. Rate = 20 lpm
Acetone	750	**0.1**	**0.7**	**1.3**	**5.2**	**10**	26
Ethyl acetate	400	**0.2**	**1.2**	**2.5**	**10**	20	49
Methyl ethylketone	200	**0.5**	**2.5**	**4.9**	20	39	98
Butyl acetate	150	**0.7**	**3.3**	**6.5**	26	52	131
Methylene chloride	100	**1.0**	**4.9**	**10**	39	79	196
Toluene	100	**1.0**	**4.9**	**10**	39	79	196
Ammonia (STEL)	35	**3**	**14**	28	112	224	561
Acetic acid	10	**10**	49	98	393	785	1963
Benzene	10	**10**	49	98	393	785	1963
Diethylamine	10	**10**	49	98	393	785	1963
Trimethylamine	10	**10**	49	98	393	785	1963
Ethyl acrylate	5	20	98	196	785	1570	3926
Phenol	5	20	98	196	785	1570	3926
Pyridine	5	20	98	196	785	1570	3926
Formaldehyde	3	33	164	327	1309	2617	6544
Acrylonitrile	2	49	245	491	1963	3926	9815
Aniline	2	49	245	491	1963	3926	9815
Carbon tetrachloride	2	49	245	491	1963	3926	9815
Benzyl chloride	1	98	491	982	3926	7852	19631
Ethylene oxide	1	98	491	982	3926	7852	19631
Nitrobenzene	1	98	491	982	3926	7852	19631
Chlorine	0.5	196	982	1963	7852	15705	39262
Methyl mercaptan	0.5	196	982	1963	7852	15705	39262
Acrolein	0.1	982	4908	9815	39262	78524	196309
Phosgene	0.1	982	4908	9815	39262	78524	196309
Toluene diisocyanate	0.005	19631	98155	196309	785238	1570475	3926188

Table 2. Sample of Laboratory Scale Generation Rates

Source	Generation Rate
Fugitive emissions and Hood Escape	<0.1 lpm
Evaporation and Spills	0.1-1 lpm
Boiling/mixing/stirring	8 lpm
Leaking or Failed Compressed Gas Cylinders	20 lpm – 1400 lpm

In realization of the difficulty of providing safe room concentrations with only room ventilation, the AIHA/ANSI Z9.5 American National Standard for Laboratory Ventilation states that use of an ACH is not an appropriate concept for designing laboratories.

Besides the total ventilation rate as given by the ACH value, attention should also be given to increasing ventilation effectiveness to ensure good use of the provided ventilation. Ventilation effectiveness can be increased with proper choices and placement of supply air diffusers. Ventilation effectiveness will be the subject of another Task Sheet.

Determining Airflow Rates for Laboratories

It is proposed that laboratory designers not specify a required minimum value for ACH for laboratories as has been used in the past, such as 10 ACH. Instead of a required minimum, it is proposed to provide guidelines for determining minimum airflow rates for laboratories and to require calculation and reporting of the resultant value for ACH. The following proposed guidelines are recommended criteria for the establishment of minimum airflow rates in laboratories and methods to calculate the resultant ACH:

- Potential sources of contaminant emission should be identified and exposure control devices including laboratory exhaust hoods should be specified as appropriate to control emissions at the source. All sources and assumptions should be clearly defined at the time of design.

- Laboratory airflow rates should be based by definition on total exhaust flow for negatively pressurized laboratories and total supply flow for positively pressurized laboratories. All lab areas having potential for release of hazardous airborne contaminants should operate under negative pressure with respect to adjacent non-laboratory spaces. The required pressure differential between the spaces should be defined by the design team, or as specified on the design documentation approved and released for construction.

- The required exhaust flow should be sufficient to satisfy the exhaust demands of all laboratory hoods and exposure control devices (within the lab) operating under all modes of operation; including occupied and unoccupied operation modes (chemical fume hood sashes open or closed), full heating and cooling modes, and emergency modes of operation. Emergency modes of operation may include fire, smoke or "shelter in place" scenarios.

- The volume of air supply to the laboratory should be sufficient to meet indoor air quality (IAQ) requirements as specified by ASHRAE and other applicable codes and standards. In the Seattle area, the International Mechanical Code (IMC) and the Washington State Indoor Air Quality Code. The laboratory should operate with 100% outside air for the supply flow.

- The quality, quantity and conditioning of the air supply should maintain the lab environment's comfort, temperature, and humidity specifications accounting for seasonal fluctuations.

- The accuracy and precision of the airflow control systems should be sufficient to maintain the required specifications for exhaust, air supply and transfer air volumes (difference between supply and exhaust). The airflow requirements of the exposure control devices shall never be compromised regardless of operating mode.

- The transfer air should be mechanically supplied, of equal quality to lab supply air, and free of hazardous contaminants. The control of transfer air quantities should prevent the spread of contamination between laboratories in the event of spill or other emergency conditions.

- In the event of large accidental releases in the laboratory room, away from exhausts and control systems, the laboratory owner should specify appropriate evacuation protocols.

Calculating Air Change per Hour Rate (ACH)

Although a minimum air change rate for dilution ventilation is not recommended, it is still suggested that the resulting air change rate be calculated. The ACH rate may be useful for evaluating a particular release scenario sometime in the future. Following the above guidelines, the required exhaust flow and supply flow should be established and the resultant ACH rate be calculated at the boundaries of airflow required for each mode of operation.

Example:

The formula to calculate the resultant ACH rate for a negatively pressurized lab should be: *(See Figure 1)*

ACH = ($\sum$ of Exhaust Volumes / Room Volume) x 60

Where: Exhaust in Cubic Feet per Minute (CFM)
Room Volume[1] in Cubic Feet (FT^3)

Constant (60 Minutes per Hour)

The formula to calculate the resultant ACH rate for a positively pressurized lab shall be:

ACH = $(\sum \text{ of Supply Volumes} / \text{Room Volume}) \times 60$

Where: Supply in Cubic Feet per Minute (CFM)
Room Volume[1] in Cubic Feet (FT^3)
Constant (60 Minutes per Hour)

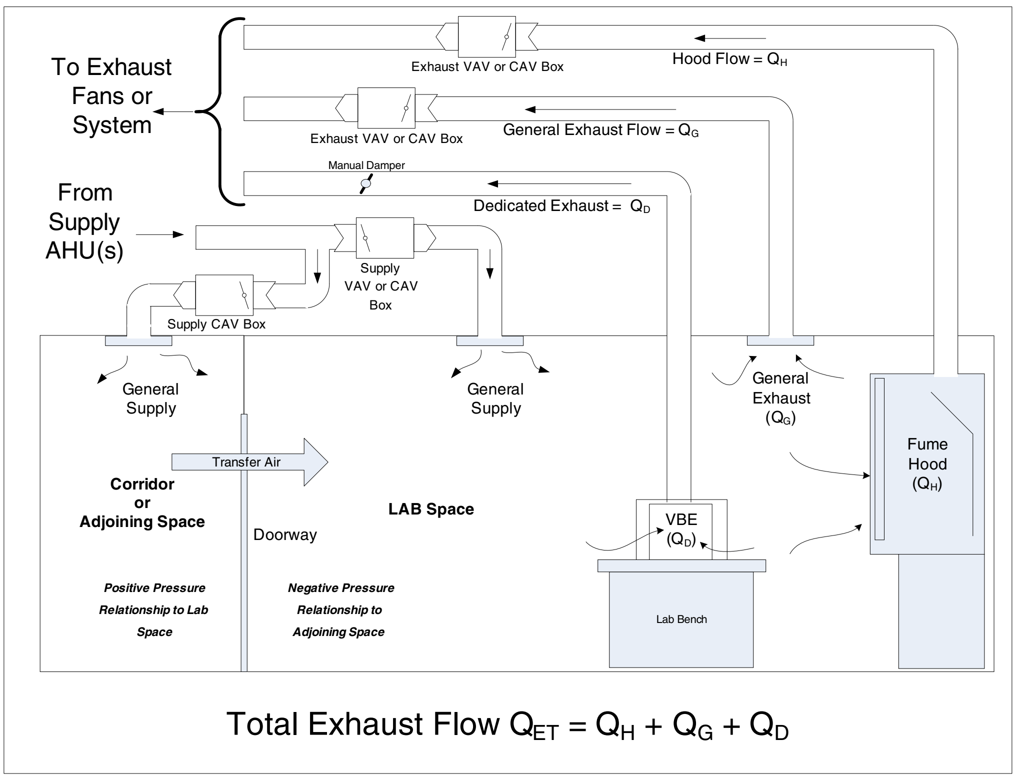

Figure 2. Lab Spaces may have multiple fume hoods, multiple general exhaust grilles, and multiple devices requiring dedicated exhaust. To calculate ACH based on exhaust for negatively pressurized labs, all exhaust sources must be included in the summation.

---

1. If the laboratory is to be furnished with vary large equipment, cabinetry, or other furniture, the volume of these items can be subtracted from the room volume. The actual ACH rate can be significantly higher than calculated value if the volumes of these furnishings are not considered. If there is no ceiling (i.e. exposed ductwork), a nominal ceiling height of 10 ft should be substituted.

Establishment of minimum airflow rates in accordance with the above guidelines when combined with adherence to good work practices and use of the lab within the operating constraints defined during design will provide safe and comfortable lab environments. However, the airflow rates or use of an ACH within limits generally recommended will not guarantee adequate dilution of chemicals to safe levels that may be produced during accidental spills in the lab, a serious breach in hood containment, the failure of gas cylinders, or contaminates generated during hazardous procedures conducted outside the confines of an approved exposure control devices. As such, emergency procedures including evacuation of the lab should be followed in accordance with laboratory owner policies.

For special areas where secondary containment (negative pressurization) is critical or must be assured following an accidental release of hazardous materials (i.e. high hazard laboratory using highly infectious or chemical warfare agents or a clean room using large quantities of hazardous chemicals) use of a separate purge system may be considered beneficial. The purge mode could be activated manually using a key pad at the exit of the laboratory. Upon initiating the purge mode, the exhaust flow would increase to achieve a greater offset volume to maintain or achieve (in the case of a clean room) a negative room pressure. Due to the costs and complexity of the systems, the practicality and benefits of a separate purge system should be scrutinized and applied only where appropriate.

Summary

It is recommended that a traditional fixed minimum air change rates, such as 10 ACH, not be used for laboratory design and operation. This value can be imprudent and provide a false sense of safety for the lab occupants and operators. Instead, air change rates should be specified considering the specific needs of a laboratory for exhaust flow, ordinary indoor air quality, thermal comfort and other considerations. The resulting ACH value should be calculated after the design process as a baseline tool for facilities management.

With the fume hood being the primary exposure control device and the lab space being the secondary containment, occupants and /or operators must understand that simply increasing the ACH rate will not prevent exposures during spills or other emergencies. Exiting the laboratory space until contaminate levels reach the LOC is the appropriate action to be taken.

References

Corbyn, Z. "Experimenting with Efficiency", *Nature*, Vol 445, February 2007.

Johnson, G.R. "HVAC Design for Sustainable Labs", *ASHRAE Journal*, September 2008.

Carpenter, J.P. "Designing for Actual Not Theoretical HVAC Requirements in Laboratory Facilities", *Labs for the 21st Century Annual Conference*, October 2007, Charleston, SC.

ANSI/AIHA. "*Laboratory Ventilation; Standard Z9.5-2003*", American National Standards Institute/American Industrial Hygiene Association. 2003.

Phillips, D.A. and Smith, A.L. "From Inside to Outside: Use of Sophisticated Modeling Tools to Optimize Laboratory Ventilation", *Labs for the 21st Century Annual Conference*, October 2006, San Antonio, TX.