Better Buildings Alliance - Laboratories Project Team

Getting Below Six Air Changes:

Highlights from BBA members who optimized air change rates in labs

Updated 1-4-13

1 Introduction

Laboratories are highly energy intensive, often using four to six times more energy per square foot than a typical office building. One of the key factors affecting energy use in labs is the minimum air change rate (ACR) requirement. Existing standards and guidelines provide wide latitude in determining minimum ACR in labs (see appendix A). For example, the Occupational Safety and Health Administration specifies a room ventilation rate of 4 to 12 air changes per hour (ACH), which "is normally adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control." The ASHRAE lab design guide has similar recommendations. Other standards recommend greater than 8 ACH. This range is very broad and provides stakeholders with little guidance on how to select an appropriate ACR. As a result, the highest value from the range is often chosen, with the implicit assumption that "more is better". Standard practice also entails the blanket adoption of ventilation guidelines as constant values, with the ACR rarely being dynamically controlled or otherwise tailored to the occupancy or conditions of the site, or optimized for energy efficiency or safety. The result can be excessive (or inadequate) ventilation for the lab in question, causing unnecessary energy expenditures.

The purpose of this document is to provide highlights from Better Buildings Alliance (BBA) members that have optimized minimum ACR to reduce energy use while maintaining or improving safety – especially cases where the ACR has been reduced below 6 ACH[1].

2 Cornell University

2.1 Approach

Cornell University has a multi-phase plan for energy conservation, with a goal is to reduce their annual energy use by 20% compared to that of year 2000. A significant portion of the savings can come from reducing laboratory ventilation system energy use (fan power, cooling and heating of outside air). They retrofitted and reduced the lab ACR from 8/4 ACH (occupied/unoccupied) to 6/3 ACH in one of their biotechnology laboratories. Cornell modified the general exhaust ductwork and relocated the registers for more effective exhaust and lower decay time. They used occupancy sensors to reduce the ACR during unoccupied times. Figures 1 and 2 illustrate the pre- and post-retrofit configurations of the air distribution system in the lab. Computational fluid dynamics (CFD) modeling showed that after retrofit of the lab exhaust system, spills were cleared well enough at 6/3 ACH to avoid exceeding the OSHA permissible exposure limit (PEL). Before the implementation of new ACR and retrofit, the CFD modeling had shown that 8/4 ACH was not clearing the spills effectively.

[1] Note that the focus of this document is on minimum requirements for general exhaust. In some laboratories, fume hoods or thermal conditioning are the primary driver for air change rates. In such cases, the minimum ACR for general exhaust is less relevant for reducing energy use.

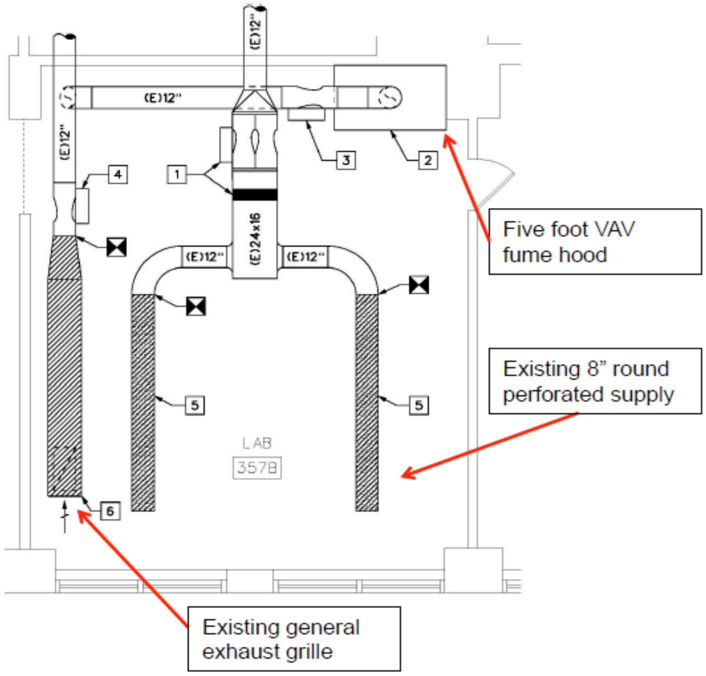

Figure 1: Air distribution layout before retrofit

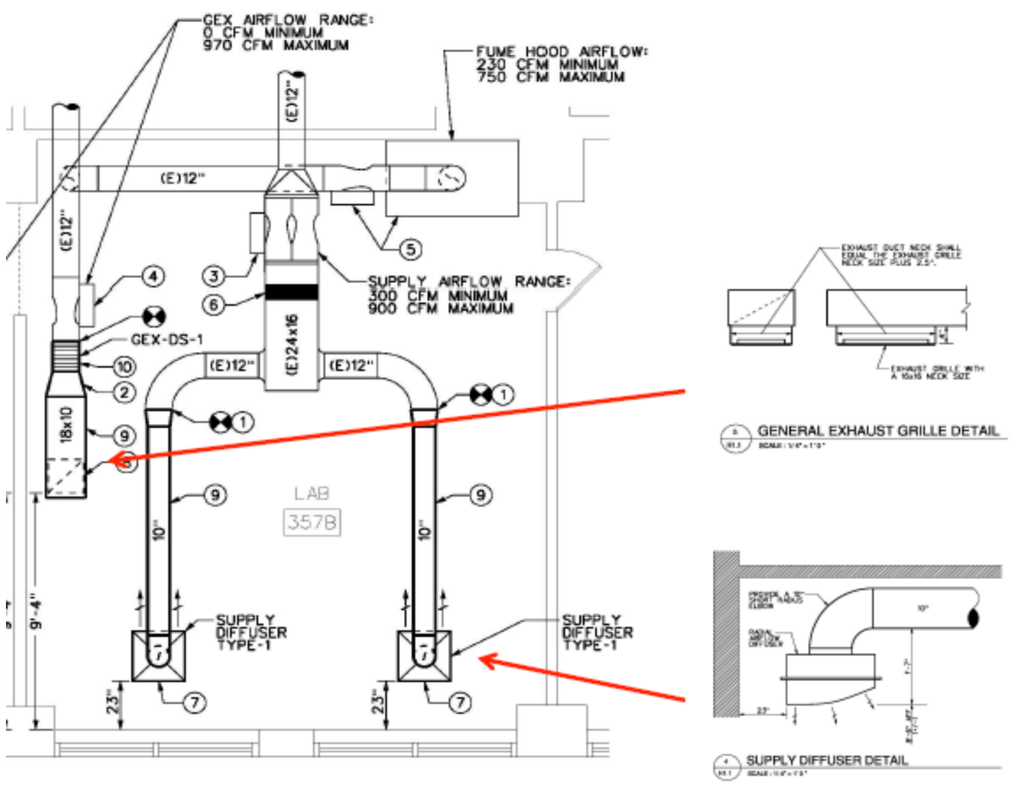

Figure 2: Air distribution layout after retrofit

2.2 Results

The retrofit included renovation of 90 fume hood zones. Annual energy costs were reduced from $1.2 million to $900,000 – a savings of $300,000 per year, and equivalent to the CO2 emissions of 100 homes. The simple payback was less than a 2 years.

Based on these results, Cornell reviewed the ACR for about 600 labs across its campus and determined that the majority can run at 6/3 ACH (occupied/unoccupied).

2.3 Additional information

Cornell also looked at open lab concept and concluded that it increases ventilation effectiveness by providing more room for chemicals to diffuse. They caution about specific areas such as edges of the room, windows, and doorways. A CO2 fire extinguisher was used to measure chemical concentration decay patterns and evaluate ventilation effectiveness at various locations in the laboratory, as figure 3 illustrates.

See the supporting documentation package for additional information.

Location of sensor	sink	table	window		BCS ach rate
Number of data points	122	126	150		
Observed ACH	34.84	37.06	32.40	per hour	38
r-squared	0.95	0.97	0.98		
Concentration half life	1.19	1.12	1.28	minutes	

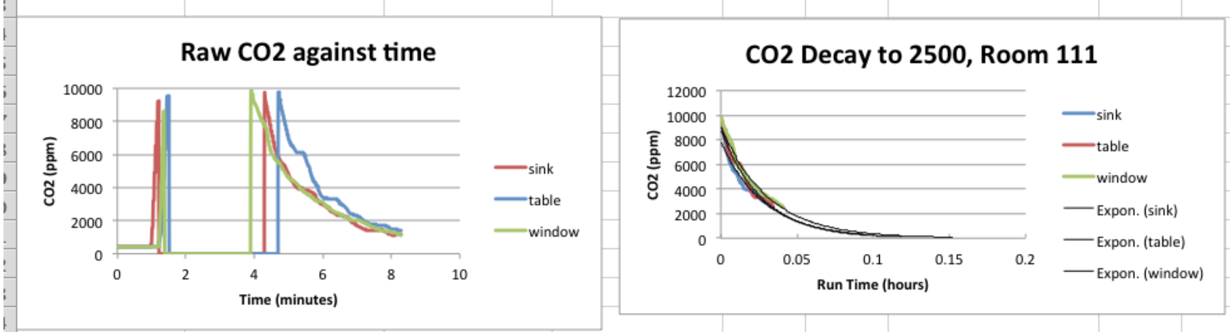

Figure 3: CO2 decay analysis

3 University of California, Irvine

3.1 Approach

UC Irvine recognized that laboratories have the potential to be far more efficient without sacrificing occupant safety if the laboratory's variable air volume features and digital controls can be integrated with advanced air quality and occupancy sensors driving smarter control logic [2]. They use real-time air quality sensing and vary ventilation rates on a zone-by-zone basis, from 2 ACH unoccupied to 4 ACH under normal occupied conditions, and peaking to 12 ACH when threshold levels of particulates, volatile organic compounds, or CO2 are sensed. This feature was part of their integrated "Smart Labs" package of measures to reduce laboratory energy use.

3.2 Results

UC Irvine's Smart Labs program, of which reducing air change rates by utilizing centralized demand controlled ventilation and exhaust stack discharge velocity reduction are key attributes, has resulted in average savings of savings of 58% across several laboratory buildings (see figure 4). The electrical savings average is 55% while the thermal savings averages 78%. UCI attributes the large thermal savings component to more closely matching the air change rate to the actual load of the space, eliminating almost all reheat.

More information and resources about UC Irvine's Smart Lab program is available at: http://www.ehs.uci.edu/programs/energy/index.html.

Laboratory Building		BEFORE Smart Lab Retrofit			AFTER Smart Lab Retrofit		
Name	Type	Estimated Average ACH	VAV or CV	More efficient than code?	kWh Savings	Therm Savings	Total Savings
Croul Hall	P	6.6	VAV	~ 20%	41%	60%	55%
McGaugh Hall	B	9.4	CV	No	40%	66%	47%
Reines Hall	P	11.3	CV	No	70%	76%	72%
Natural Sciences 2	P,B	9.1	VAV	~20%	48%	62%	50%
Biological Sciences 3	B	9.0	VAV	~30%	45%	81%	60%
Calit2	E	6.0	VAV	~20%	46%	78%	62%
Gillespie Neurosciences	M	6.8	CV	~20%	58%	81%	61%
Sprague Hall	M	7.2	VAV	~20%	58%	82%	71%
Hewitt Hall	M	8.7	VAV	~20%	58%	77%	69%
Engineering Hall	E	8.0	VAV	~30%	59%	78%	61%
Averages		**8.2**	**VAV**	**~20%**	**55%**	**76%**	**58%**

Type: P = Physical Sciences, B = Biological Sciences, E = Engineering, M = Medical Sciences

Figure 4: Savings from Smart Lab retrofit, which includes reducing ACR to 4/2 ACH (occupied/unoccupied)

[2] Wendell Brase. "Smart Laboratories Cut Energy Consumption by Half". University of California Irvine. April 2012. Available at http://www.ehs.uci.edu/programs/energy/index.html. Accessed January 4, 2013.

4 University of Colorado, Boulder

4.1 Approach

The University of Colorado Boulder (CU) conducted a review of applicable codes and standards and determined that there is no prescribed ACH that determines a safe lab, except for ‘H’ occupancies. CU was able to establish a comfort level in lab safety with a performance-based approach incorporating lab safety protocol, spill risk analysis, and lab hazard classification. Using this approach they were able to use 4 ACH in low hazard labs and 6 ACH in high hazard labs.

CU evaluated the lab hazard assumptions in the event of a spill with two approaches: modeling using mathematical calculations, and real time monitoring with mock spill scenario using acetone (figure 5). The acetone concentration over time was compared to occupational exposure limits to evaluate the hazard level. These tests were performed in different labs with current and revised air change rates.

Figure 5: Acetone spill test

4.2 Results

The pilot study to reduce ACR was performed in a 137,000 sf laboratory building. The estimated annual energy savings was 38% including heating and cooling. The project cost was $125,000. Annual energy savings were estimated to be $60,000, which results in an estimated simple payback of 2 years. CU estimates an average of 15-19% if the reduced ACR are applied for all labs on campus.

4.3 Additional information and documentation:

For the spill analysis, modeled data are more conservative (figure 6). Lower ACR shows elevated concentrations over time, however they never exceed current OSHA occupational exposure limits (OELs). While the higher ACR maintains a lower acetone concentration, the lower ACR had a comparable amount of time to evacuate the space to < 10 ppm.

See the supporting documentation package for additional information.

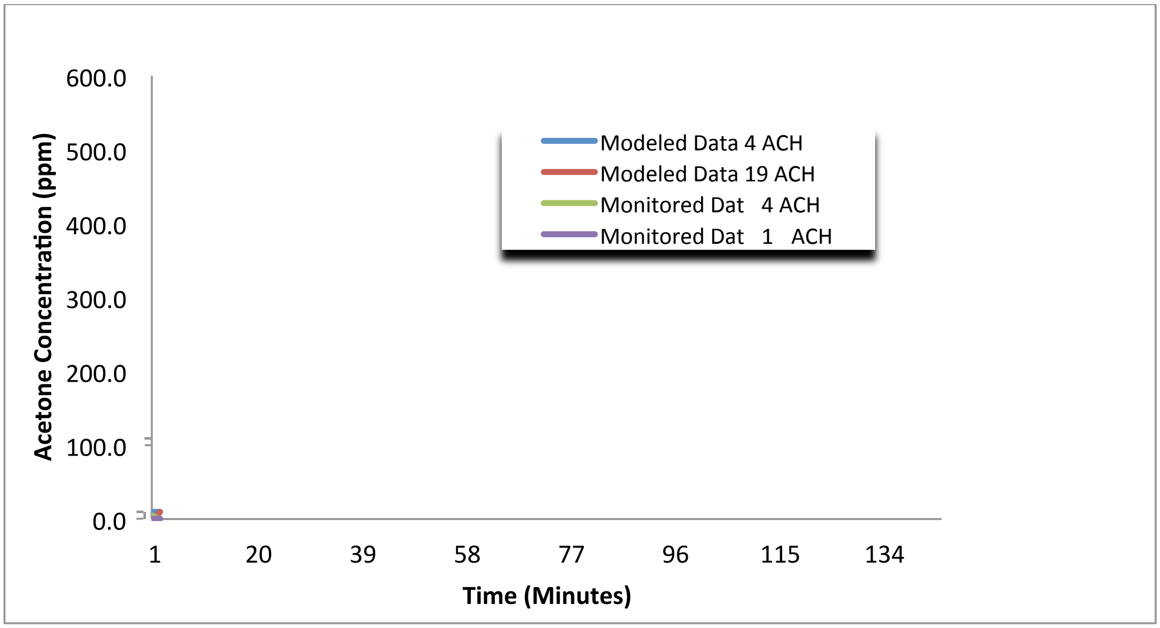

Figure 6: Comparison of modeled and monitored spill test data.

5 Key takeaways to optimize ACR in your laboratories

The following are a few key takeaways based on the above examples and other Labs21 resources:

1. Conduct a careful risk analysis of lab hazards in each lab and set the ACR for each lab based on these analyses, rather than a general blanket assumption about risks.
2. Ensure that the Authority Having Jurisdiction (AHJ) is fully engaged with efforts to optimize ACR.
3. Consider CFD modeling and/or real-time monitoring to evaluate whether lower ACR will provide adequate decay times for normal operations and/or for spill scenarios.
4. Install occupancy sensors to control occupied /unoccupied air flows. This is a simple retrofit with major impact on energy use.
5. If needed, modify the location and type of supply diffusers and exhaust registers for more efficient air flows and velocities.
6. Re-balance the system and re-commission control systems periodically. Even if initial commissioning was done properly, changes in systems, layout of the room, and hazard conditions can make the current operation inefficient.
7. Implement major infrastructure retrofit such as converting all of the air systems to VAV and convert the control system to DDC controls with more monitoring capabilities, tighter control, and faster reaction times.
8. In fume hood-driven labs, ACR is normally higher than the level required for general exhaust. To reduce ACR, reduce face velocity on hoods that can maintain containment at lower flow rates, either through VAV or low flow hoods. Modify or replace hoods with low flow hoods. Identify hoods that can be removed or hibernated.

Standard ACR practice optimizes neither safety nor energy efficiency. While predefined code- or standards-based approaches are the most straightforward, they do not optimize a laboratory's ACR rate, or verify whether the intended levels of safety and comfort have been achieved. Good ventilation design practices, which involve in-depth analyses of users' tasks, the location of tasks within a laboratory, and careful risk analysis, translate into higher energy efficiency, lower life-cycle cost, and, most importantly, enhanced safety.

6 Acknowledgements

The BBA Laboratories Team would like to thank the following team members for presenting and sharing the information presented in this document:

Cornell University: Ralph Stuart, Lanny Joyce

University of California Irvine: Wendell Brase, Matt Gudorf, Scott Jackson, David Kang, Lisa Mahar

University of Colorado Boulder: Shannon Horn, Timothy Lockhart, Kathryn Ramirez-Aguillar

For more information, contact the Laboratories Project Team:
Paul Mathew, Lawrence Berkeley National Laboratory
pamathew@lbl.gov (510) 486 5116

Appendix A: Codes and Standards

Table 1: Design codes with air change rate requirements

Code	Ventilation Rate	Comment
IBC -2004	1 CFM/ft2 for H-5	Section 415.9.2.6
IMC - 2004	1 CFM/ft2	Rate required for storage areas that exceed maximum allowable quantities of hazardous materials. (Section 502.8.1.1.2)
UBC - 1997	1 CFM/ft2 for H-6	Uniform codes have been replaced by international codes beginning in 2000. (Section 1202.2.5)

Table 2: Common design standards with air change rate guidelines

Standard	Ventilation Rate	Comment
ANSI/AIHA Z9.5	The specific room ventilation rate shall be established or agreed upon by the owner or his/her designee.	The latest version of the American National Standards Institute and the American Industrial Hygiene Association standard (ANSI/AIHA Z9.5-2003, Section 2.1.2) states that a method based on "air changes per hour is not the appropriate concept for designing containment control systems. Contaminants should be controlled at the source." ANSI/AIHA also states that the air changes per hour do not "reflect actual mixing factors" of a particular room.
NFPA-45-2004	Minimum 4 ACH unoccupied; occupied "typically greater than 8 ACH"	According to the National Fire Protection Association's Standard NFPA 45, Appendix A: A 8-3.5 (NFPA 45 2004), room air cur rents in the vicinity of fume hoods should be as low as possible, ideally less than 30% of the face velocity of the fume hood. Air supply diffusion devices should be as far away as possible from fume hoods and have low exit velocities.
ACGIH–Ind. Vent.–24th Ed.–2001	The required ventilation depends on the generation rate and toxicity of the contaminant, not on the size of the room in which it occurs.	This standard from the American Conference of Governmental Industrial Hygienists states that "'Air changes per hour' or 'air changes per minute' is a poor basis for ventilation criteria where environmental control of hazards, heat, and/or odors is required." The impact of the laboratory's ceiling height is identified as one reason why an air change approach does not adequately address the required contamination control (Section 7.5.1, Air Changes).
ASHRAE Lab Guide–2001	4-12 ACH	The ASHRAE Laboratory Design Guide includes suggestions relating to the following: • Minimum supply air changes • Minimum exhaust air changes • Minimum outdoor air changes • Recirculation considerations
OSHA 29 CFR Part 1910.1450	4-12 ACH	The Occupational Safety and Health Administration specifies a room ventilation rate of 4 to 12 air changes per hour, which "is normally adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control." This range is extremely broad and provides a designer with little guidance.