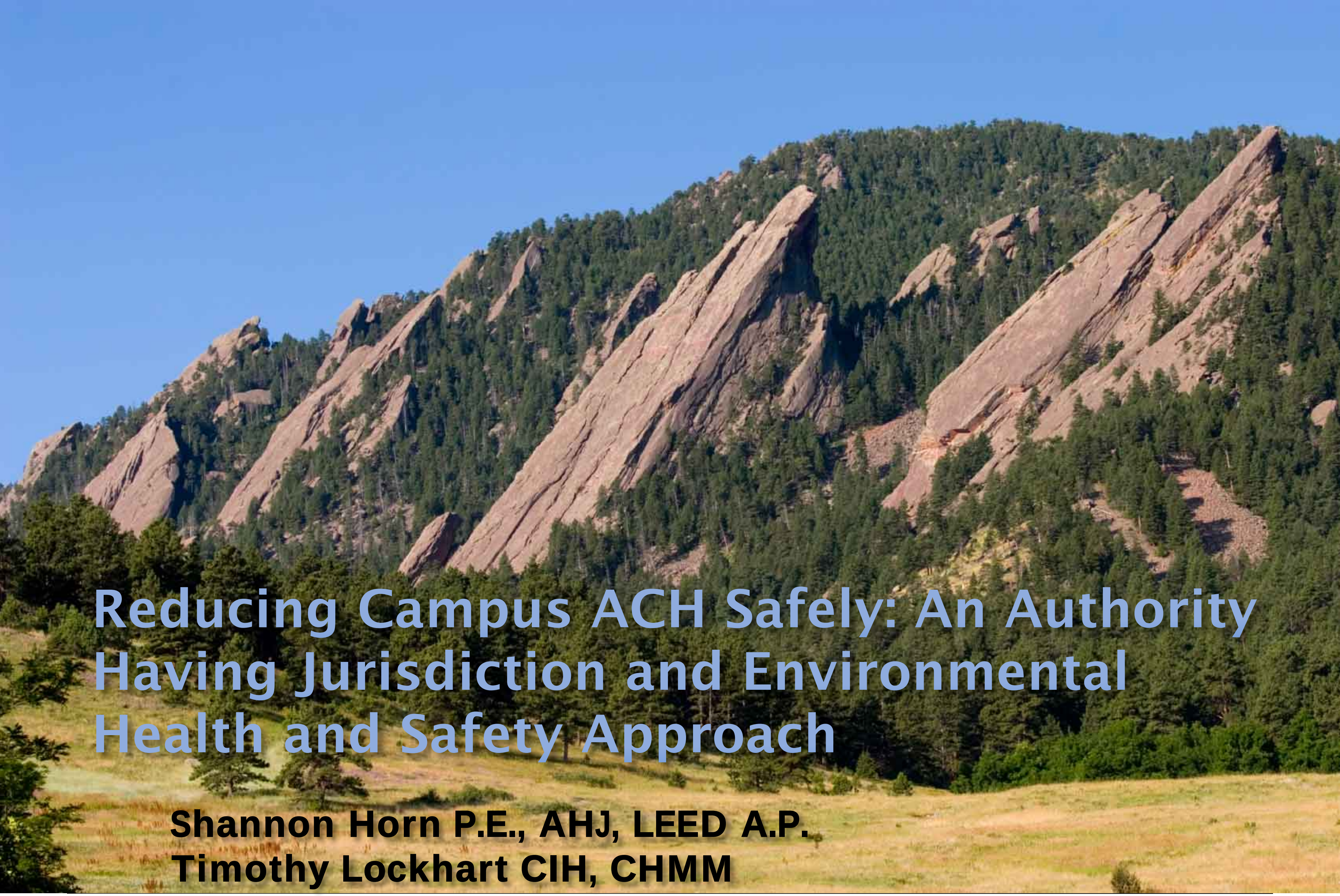


Reducing Campus ACH Safely: An Authority Having Jurisdiction and Environmental Health and Safety Approach

Shannon Horn P.E., AHJ, LEED A.P.
Timothy Lockhart CIH, CHMM

University of Colorado Boulder

Labs21 – September 2011

Learning Objectives

Participants will be able to:

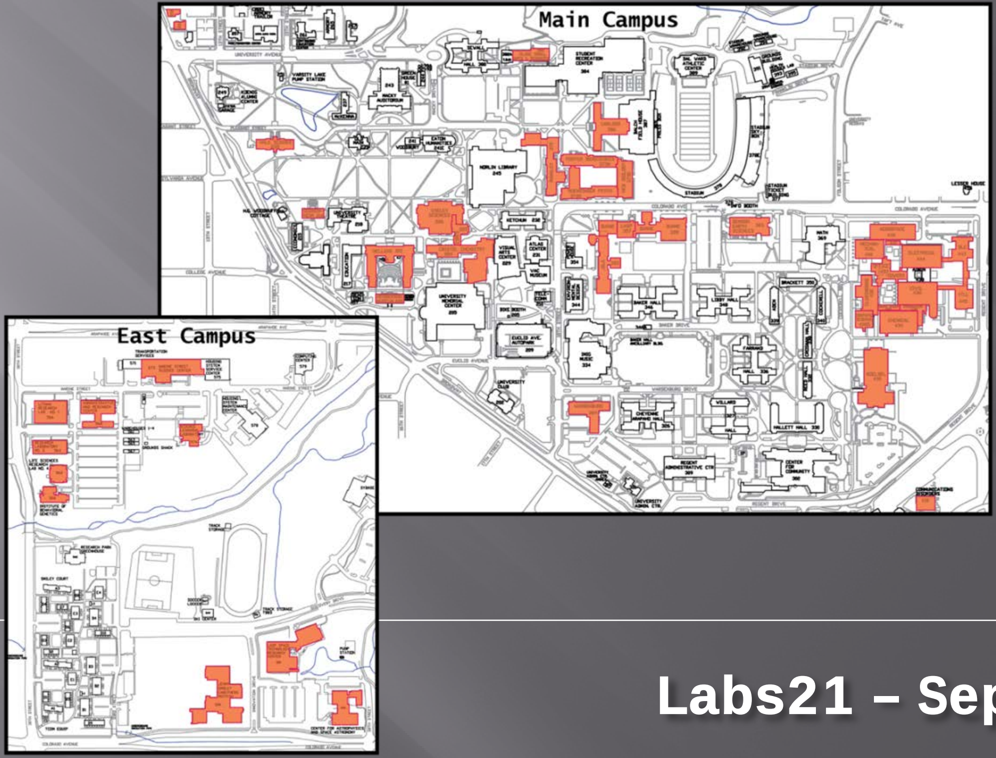
1. Provide a convincing argument to Authorities Having Jurisdiction (AHJ) and Environmental Health and Safety Departments (EH&S) (Industrial Hygienist) a performance based air change rate.

2. Identify three principle criteria that define and effect the ACH.

3. Utilize a case study of how applying a performance based ACH analysis to an existing facility will reduce energy consumption while maintaining form, fit, and function.

Background/Introduction

- The University of Colorado at Boulder has approximately 2.1 million square feet of laboratory space,
- This accounts for 22% of the total campus square footage and 43% of the total annual consumption of the entire campus.
- All labs were built in different eras with different philosophies and standards regarding Air Change Rate (ACH) and safety.



Challenge for the Campus
AHJ's and EH&S

Determine what air exchange rate is acceptable and appropriate for new and existing Laboratories on campus

- *Minimize energy consumption while maintaining form, fit, function and a safe lab environment*
- *Determine how this approach could be pragmatically applied to new and existing facilities using available resources*

Code and Standard

Review of codes and industry standards adopted by the University and the State of Colorado

- AHJ's we are obligated to follow:
  - code as a matter of law and enforcement
  - Use standards and best industry practice to make educated decisions in grey areas not covered by code.
    - ANSI, AIHA, NFPA, OSHA, IBC, IMC, IFC, ASHRAE, NIH, ACGIH

Conclusions from Code Review

There is no prescribed ACH that determines a safe lab except for H occupancies.

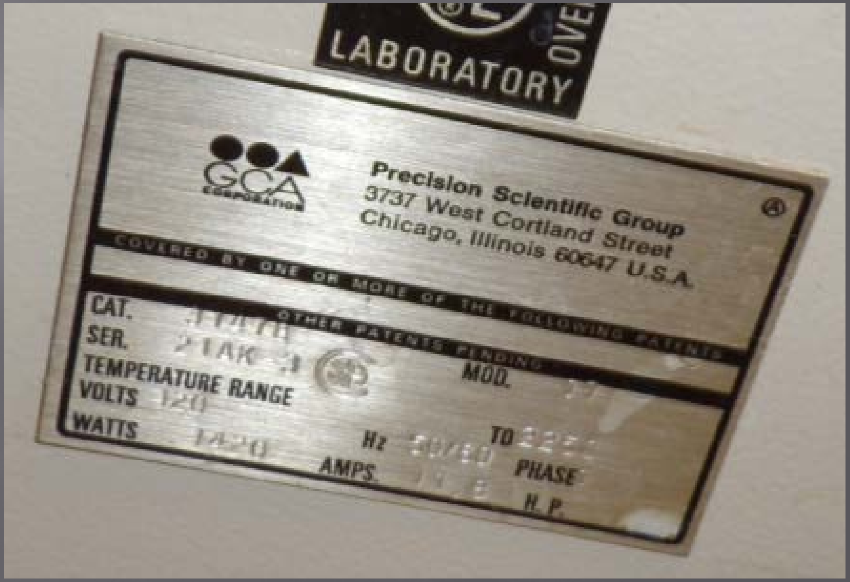
So what do we do and how do we validate it?

- Code and standard review indicate a performance based air change rate is best approach
- 3 main variables for ACH in laboratories effecting performance
  - Loads
  - Hood Ventilation Needs
  - Hazard classification based on type of research and compounds used

Internal Loads in Labs

Loads were determined by:

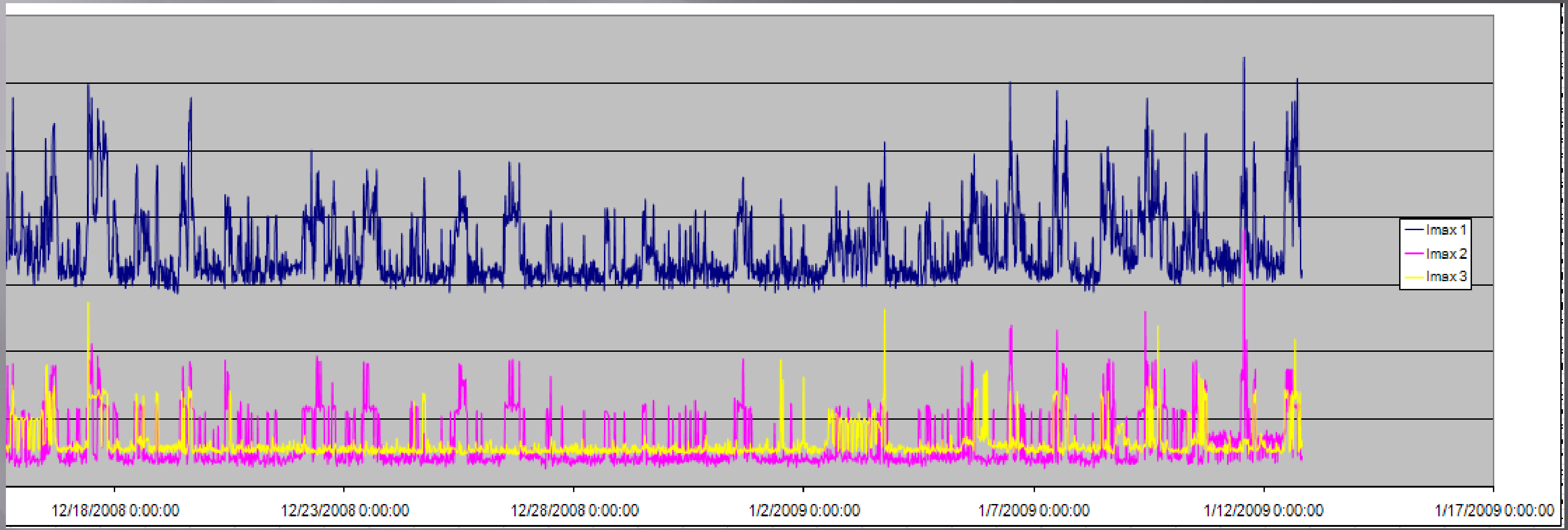
- Surveying all equipment in a space, taking name plates and if there were no name plates researching similar devices



Measured Labs

Loads were determined by:

- Metering a sample of typical and representative labs throughout campus (i.e. engineering labs, chemical, molecular/biological and hybrid labs)



Lab Watt Per Square foot

Loads were determined by:

- Determining a diversity factor for similar types of labs by reviewing the surveyed data with the actual measured data
- Included envelope needs as applicable
- Compared above items with the Labs 21 database as another point of reference to compare information

Items considered to minimize the load variable further:

- Work with lab users to use/purchase different equipment
- Turn off equipment or set back when not in use
- Consider infrastructure changes such as fan coil units to remove the loads from impacting the ventilation rate.

Hood Ventilation in Labs

Ventilation needs determined by:

- Hood face velocities Campus Standard
  - 100 fpm for non-low flow high performance hoods
  - 60 to 70 fpm for low flow high performance hoods
  - 80 fpm for retrofit kits for standard hoods to convert

Options considered to minimize the Hood ventilation:

- Replace the Hood to a low flow high performance hood
- Retrofit the hood
- Leave as is
- Convert to a VAV system if constant volume

Hazard Classifications in Labs

- Hazard classifications
  - NFPA guidelines
  - Surveys of lab activities
- Hazard classifications were categorized
  - high (6 ACH)
  - low (4 ACH)

How do we validate the hazard air change rate assumption while establishing some level of safety in the event of a spill and addressing concerns of low level chronic exposure?

EH&S Pragmatic Evaluation and Approach

3 variables evaluated to establish a level of safety for reduced ACH:

1. ***Lab protocol and management***

2. ***Risk analysis***

3. ***Quantify potential exposures:***
   - Modeling - mathematical calculations
   - Monitoring - mock spill scenario and real time monitoring of space

UCB Lab Protocol and Management:

Laboratory staff are trained to understand:

1. Understanding compound hazard
2. Differences between hazard classes (NFPA)
3. Incidental spills vs. catastrophic spills
4. Fume hoods used for high hazard compounds
5. Evacuation of the space in the event of a spill

Risk Analysis

- The campus has reported approximately 1 evacuation event per year for 2.1 million square feet of laboratory space.

- Based on this data point the University has *less* than a 1% chance based on any given lab evaluated that the incident will occur in a particular space.

- If an event does occur the exposure is limited further by the evacuation procedures in place.

Quantify Lab Hazard Assumptions in the Event of a Spill with:

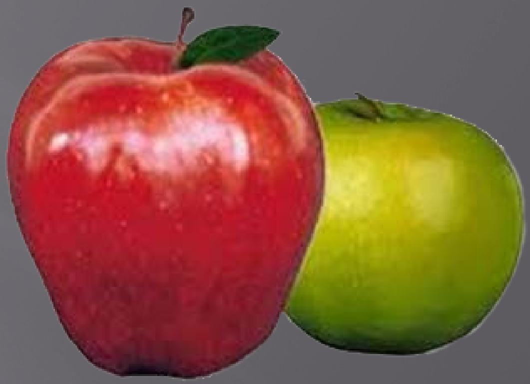
- **Modeling** - mathematical calculations

- **Monitoring** - mock spill scenario and real time monitoring of spaces

Estimating acetone concentration over time for comparison to occupational exposure limits

Modeling Vs. Monitoring

- Pros and Cons
- Assumptions
- Variables

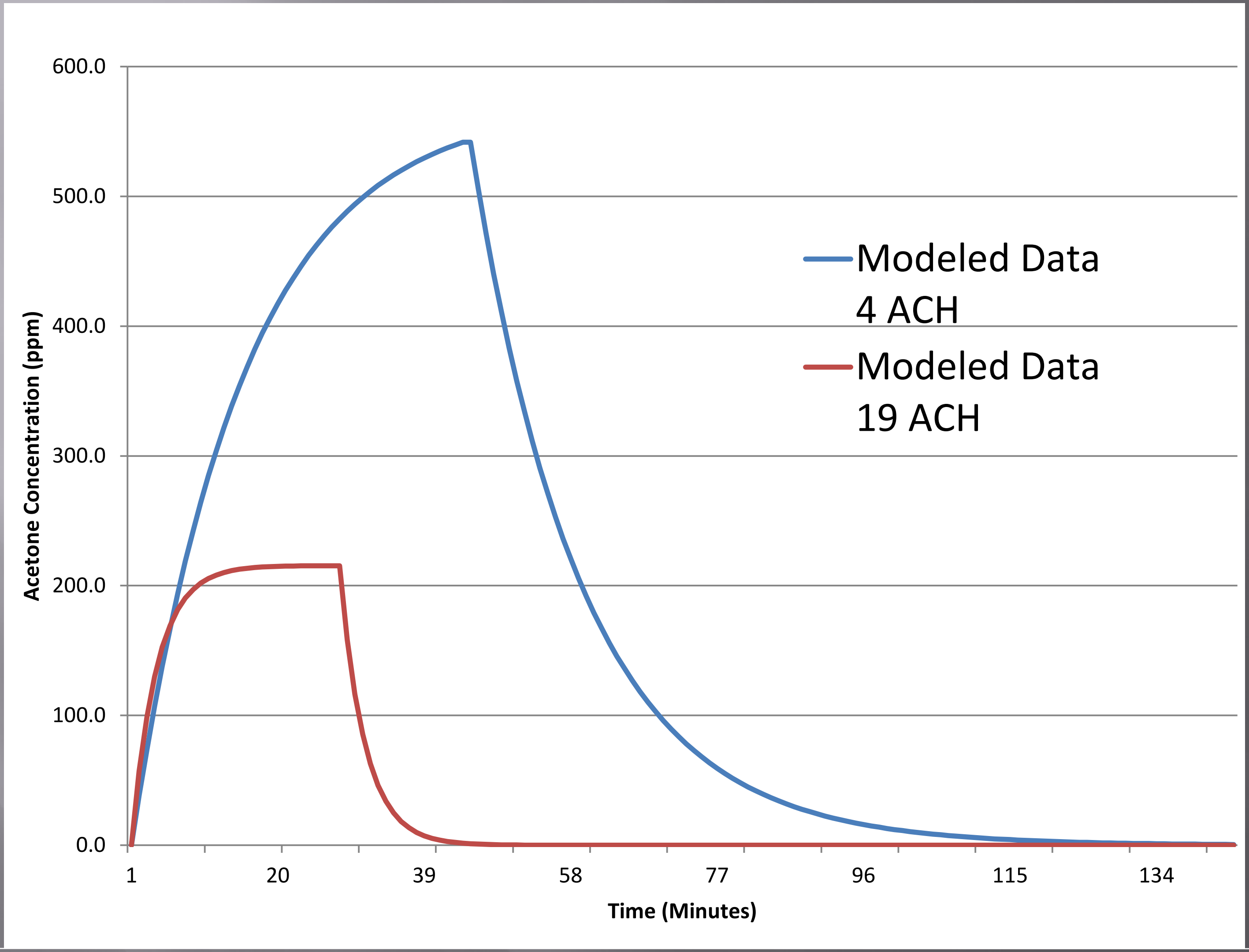


Modeling Approach

Mathematically estimate generation and degradation of acetone concentration over time for 2 different air exchange rates

(High 19 ACH vs. Low 4 ACH)

Generation and Degradation of Acetone Concentration Modeled Data (4 ACH Vs. 19 ACH)



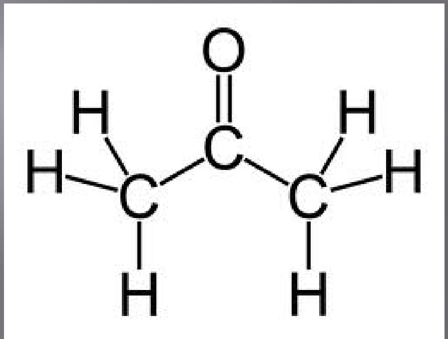
Occupational Exposure Limits

OSHA PEL – 1,000 ppm
ACGIH TLV – 500 ppm
STEL – 750 ppm
NIOSH REL – 250 ppm

Air Monitoring Approach

Location – Molecular Biology Research Facility

- Low hazard lab



Acetone

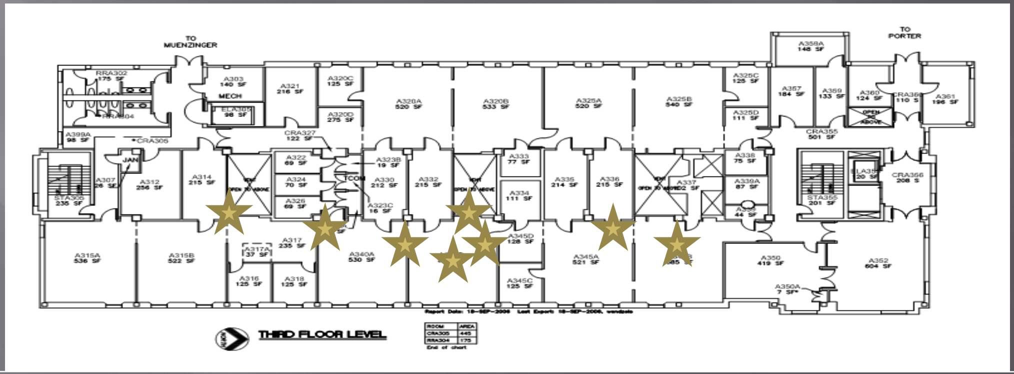
- Highly volatile
- Easily monitored
- Relatively non-toxic
- Commonly used

Real Time Air Monitoring

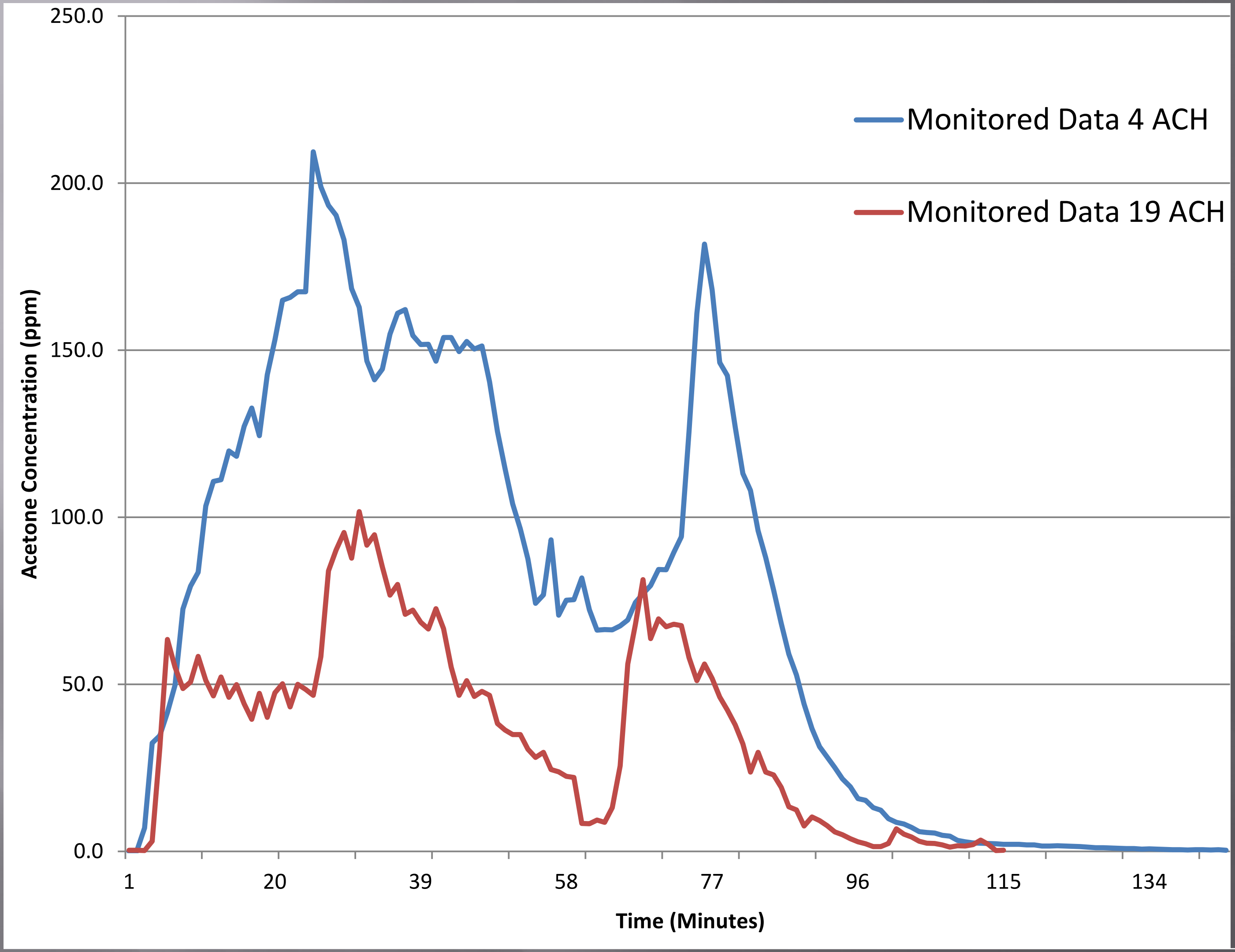
- Acetone concentration over time

Air Monitoring
Mock Spill Scenario

- 4 Liters spilled on floor of laboratory
- Spill dimensions:
  — 2.67 m^2 x 0.15 cm
- Acetone distributed in 20 cafeteria trays
- Air Monitoring
  — 8 PID (LOD 0.1 ppm)



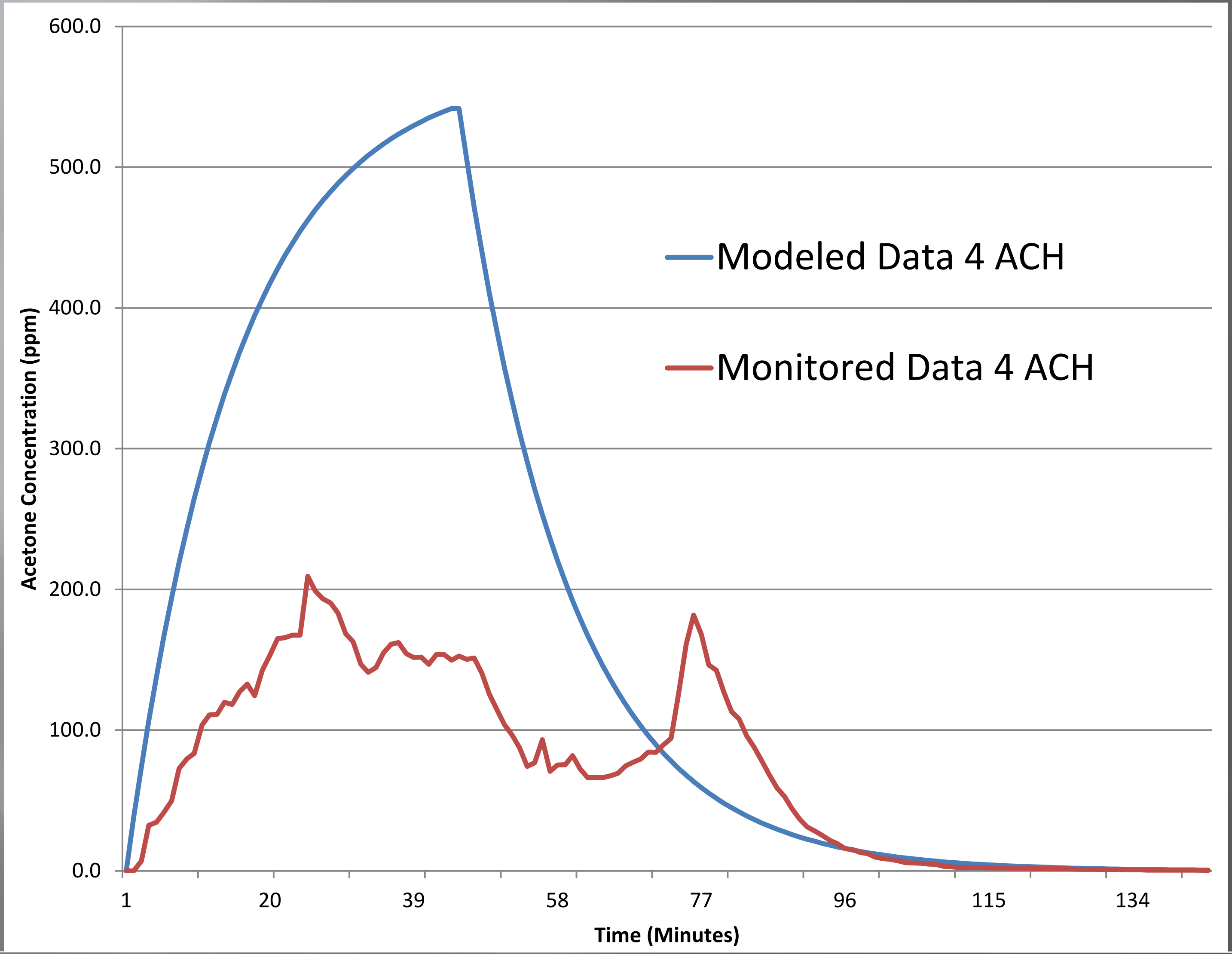
Generation and Degradation of Acetone Concentration Monitored Data (4 ACH Vs. 19 ACH)



<u>Occupational Exposure Limits</u>

OSHA PEL – 1,000 ppm
ACGIH TLV – 500 ppm
STEL – 750 ppm
NIOSH REL – 250 ppm

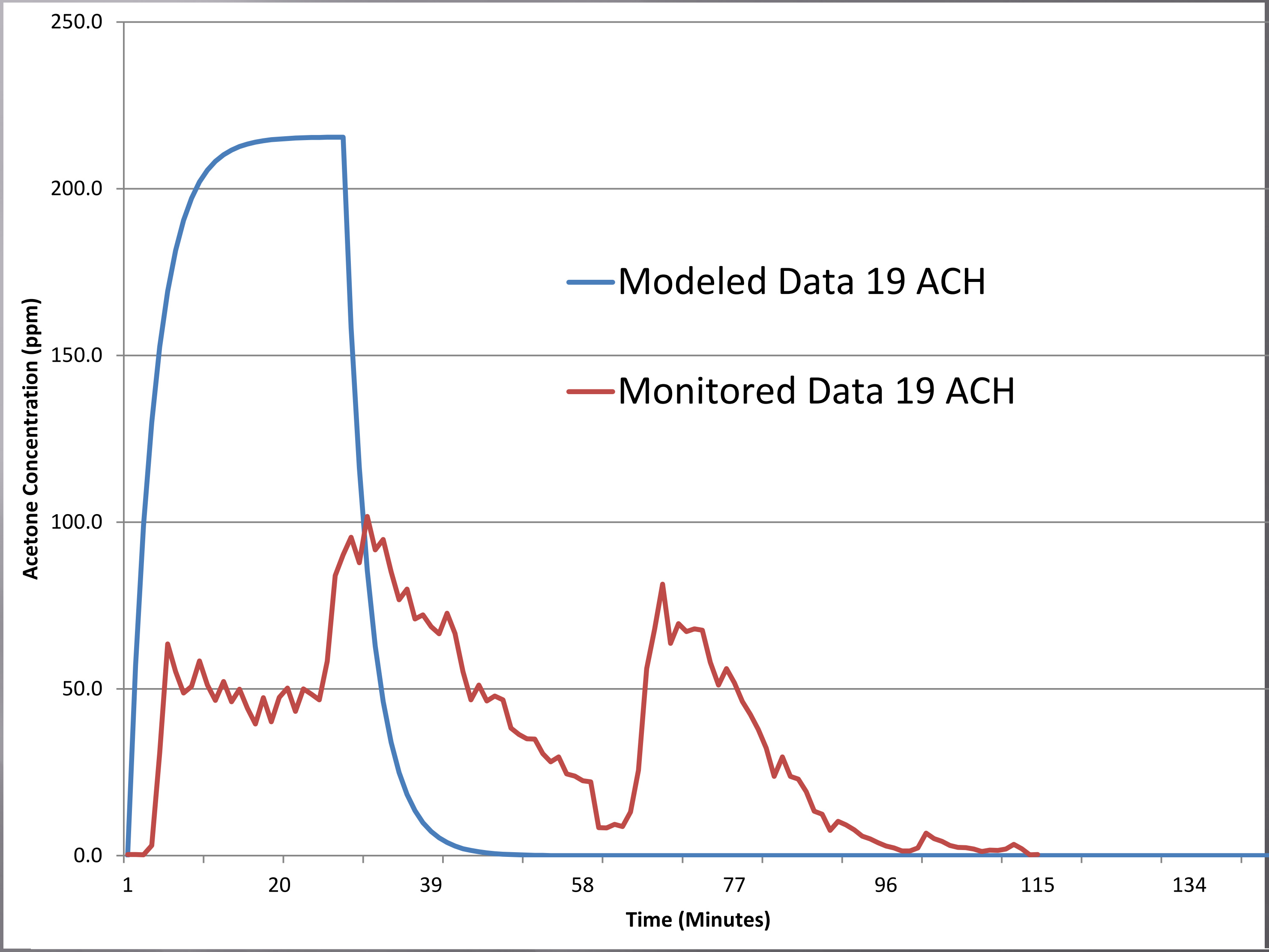
Generation and Degradation of Acetone Concentration Monitored & Modeled Data (4 ACH)



Occupational Exposure Limits

OSHA PEL – 1,000 ppm
ACGIH TLV – 500 ppm
STEL – 750 ppm
NIOSH REL – 250 ppm

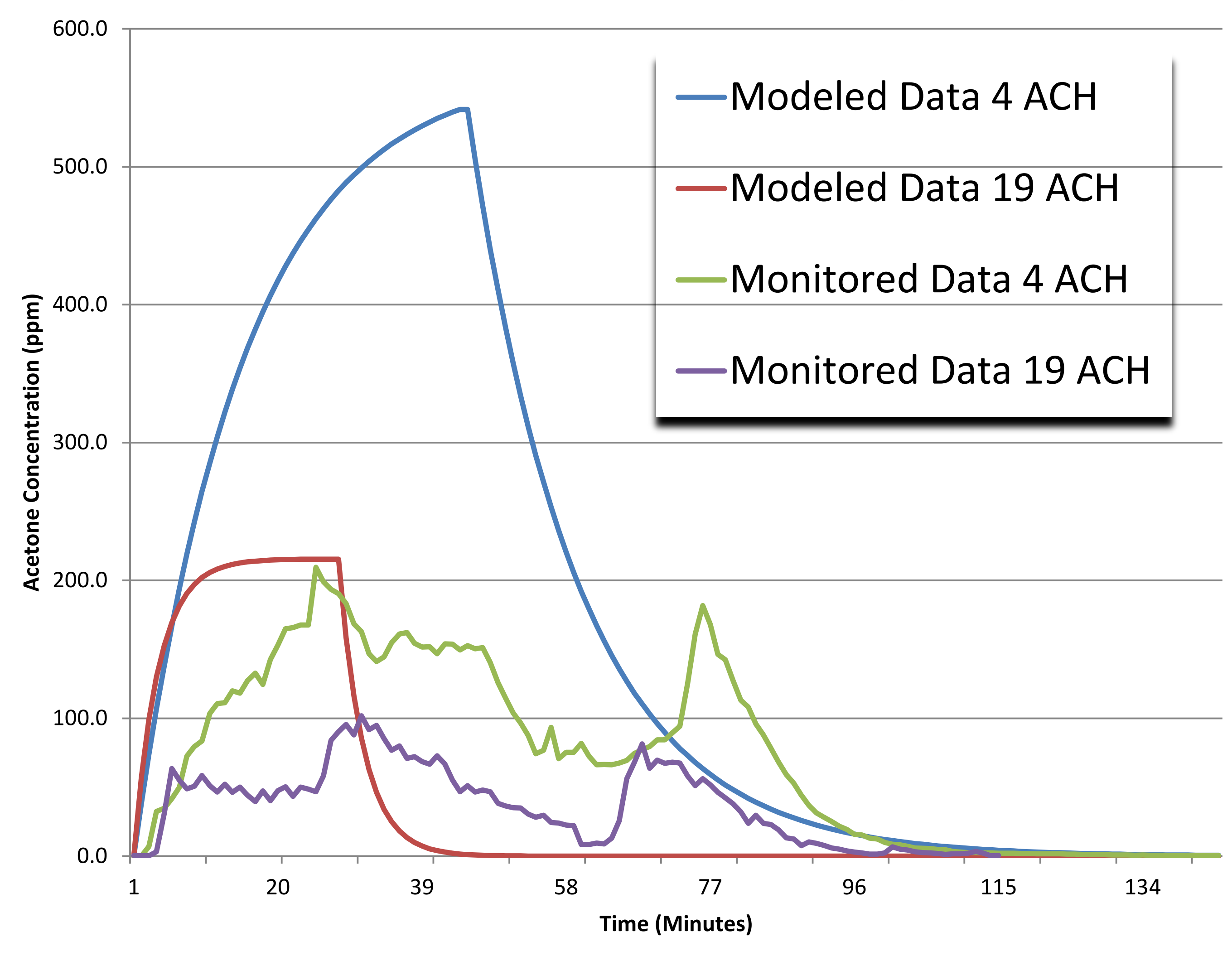
Generation and Degradation of Acetone Concentration Monitored & Modeled Data (19 ACH)



Occupational Exposure Limits

OSHA PEL – 1,000 ppm
ACGIH TLV – 500 ppm
STEL – 750 ppm
NIOSH REL – 250 ppm

Generation and Degradation of Acetone Concentration Monitored & Modeled Data (4 ACH vs. 19 ACH)



Occupational Exposure Limits

OSHA PEL – 1,000 ppm
ACGIH TLV – 500 ppm
STEL – 750 ppm
NIOSH REL – 250 ppm

Modeling/Monitoring Data Summary

1. Modeled data is more conservative
2. Lower ACH shows elevated concentrations over time however never exceeds current OELs
3. Higher ACH maintains a lower acetone concentration however the lower ACH had a comparable amount of time to evacuate the space to < 10 ppm

Is Modeling a representative approach to determining a safe Hazard ACH for labs?

Spreadsheet Analysis

All of the above went into a spreadsheet comparing the variations and variables

	A	B	C	D	V	W	X	Y	Z	AA	AE	AF	AG	AH	AI	AJ	AK
1			rooms w/ multiple hoods														
2	TB #	RM #		Sq Ft of LAB	Supply Min. VAV(cfm)	Supply (cfm)	ACH (based on design supply cfm)	Exhaust (cfm)	ACH (based on design exhaust cfm)	Cfm Balance report or drawing #	Plug W/sf Field	Plug load W	Lighting W	Pop Density (sq ft / person)	# of people	Occupant W	Total Int Load W
30	311	A340B	RESEARCH LAB	534		2000	22.5	2100	23.6	373e-001-m305	4	2136	614	100	5.34	399	3149
31		A345A	RESEARCH LAB	521						373e-001-m305	4	2084	599	100	5.21	389	3072
32	337	A345D	RESEARCH LAB	128		2000	18.5	2100	19.4	373e-001-m305	4	512	147	100	1.28	96	755
33	335	A345B	RESEARCH LAB	292.5		1000	20.5	1050	21.5	373e-001-m305	4	1170	336	100	2.93	219	1725
34	336	A345B	RESEARCH LAB	292.5		1000	20.5	1050	21.5	373e-001-m305	4	1170	336	100	2.93	219	1725
35	338	A345C	OFFICE	125		400	19.2	375	18.0	373e-001-m305	1	125	144	100	1.25	93	362
36	334	A350	CONFERENCE ROOM	419		1400	20.0	1300	18.6	373e-001-m305	0	0	482	50	8.38	626	1108
37	332,333	A352	Break Rm	604		1700	16.9	1600	15.9	373e-001-m305	1	604	695	50	12.08	903	2201
38	325	A357	RESEARCH LAB	184		2500	81.5	2500	81.5	373e-001-m305	13	2392	212	100	1.84	137	2741
39	326	A359	RESEARCH LAB	133		1600	72.2	1600	72.2	373e-001-m305	9	1197	153	100	1.33	99	1449
40	343	A359A	RESEARCH LAB	148		1000	40.5	1000	40.5	373e-001-m305	8	1184	170	100	1.48	111	1465
41	327	A360	RESEARCH LAB	124		1400	67.7	1500	72.6	373e-001-m305	0	0	143	100	1.24	93	235
42	328	A361	RESEARCH LAB	196		1900	58.2	2100	64.3	373e-001-m305	2	353	225	100	1.96	146	725
43	105	A106	Autoclave	128	375	1250	58.6	1300	60.9	373e-001-m304	10	1280	147				1427
44	117	A106	Autoclave	128	375	1250	58.6	1300	60.9	373e-001-m304	10	1280	147	100	1.28	96	1523
45	116	A108	RESEARCH LAB	217	700.00	2240	61.9	2400	66.4	373e-001-m304	4	890	250	100	2.17	162	1301
46	119	A110A	RESEARCH LAB	536	700.00	2000	22.4	2100	23.5	373e-001-m304	4	2144	616	100	5.36	400	3161
47	118	A110B	RESEARCH LAB	520	700.00	2000	23.1	2100	24.2	373e-001-m304	4	2080	598	100	5.20	389	3067
48	114	A112, A114	FACULTY OFFICE	250	240.00	800	19.2	750	18.0	373e-001-m304	1	250	288	125	2.00	149	687
49	115	A115	RESEARCH LAB	272	300.00	1000	22.1	1000	22.1	373e-001-m304	4	1088	313	100	2.72	203	1604
50	113	A117	lab	120	400.00	1300	65.0	1300	65.0	373e-001-m304	4	480	138	100	1.20	90	708
51	120	A119	lab	151	420.00	1400	55.6	1600	63.6	373e-001-m304	4	604	174	100	1.51	113	890
52	109,121,124	A120	STUDENT STUDY ROOM	474.6	540	1800	22.8	1620	20.5	373e-001-m304	1	237	546	50	9.49	709	1492
53	121	A120	STUDENT STUDY ROOM	474.6	540	1800	22.8	1620	20.5	373e-001-m304	1	237	546	50	9.49	709	1492
54	124	A120	STUDENT STUDY ROOM	474.6	540	1800	22.8	1620	20.5	373e-001-m304	1	237	546	50	9.49	709	1492
55	108	A120	STUDENT STUDY ROOM	474.6	225	750	9.5	1620	20.5	373e-001-m304	1	237	546	50	9.49	709	1492
56	122	A120	STUDENT STUDY ROOM	474.6	150	500	6.3	1620	20.5	373e-001-m304	1	237	546	50	9.49	709	1492
57		A120 total		2373	1995	6650	16.8	8100	20.5								
58	106	A121	Computer room	177	225	750	25.4			373e-001-m304	1	177	204	100	1.77	132	513
59	107	A123	CENTRAL STORAGE	216	450	1500	41.7	1400	38.9	373e-001-m304	1	216	248	500	0.43	32	497
60	110	A130	RESEARCH LAB	212	700.00	2240	63.4	2400	67.9	373e-001-m304	18	3752	244	100	2.12	158	4155
61	141	A134, A	RESEARCH LAB SERVICE	210	1050	1050	30.0	1175	33.6	373e-001-m304	1	210	242	100	2.10	157	608
62	123	A136	RESEARCH LAB	214	700.00	2240	62.8	2400	67.3	373e-001-m304	11	2440	246	100	2.14	160	2846
63	142	A139, A	storage	149		2100	84.6	2100	84.6	373e-001-m304	0	0	171	100	1.49	111	283
64	112	A140A	RESEARCH LAB	525	700.00	2000	22.9	2100	24.0	373e-001-m304	4	2100	604	100	5.25	392	3096
65	111	A140B	RESEARCH LAB	534	700.00	2000	22.5	2100	23.6	373e-001-m304	4	2136	614	100	5.34	399	3149
66	139	A145A, D	RESEARCH LAB	650	700.00	2000	18.5	2100	19.4	373e-001-m304	4	2600	748	100	6.50	486	3833
67	138	A145B	RESEARCH LAB	292.5	300.00	1000	20.5	1050	21.5	373e-001-m304	4	1170	336	100	2.93	219	1725
68	137	A145B	RESEARCH LAB	292.5	300.00	1000	20.5	1050	21.5	373e-001-m304	4	1170	336	100	2.93	219	1725
69	140	A145C	FACULTY OFFICE	125	120	400	19.2	375	18.0	373e-001-m304	1	125	144	125	1.00	75	343

Methods to Reduce ACH

Three main methods to reducing ACH were determined from this analysis:

- Re-balance the system
- Modify/replace hoods
- Modify major infrastructure (i.e. change to VAV, add fan coil units, convert to DDC controls)

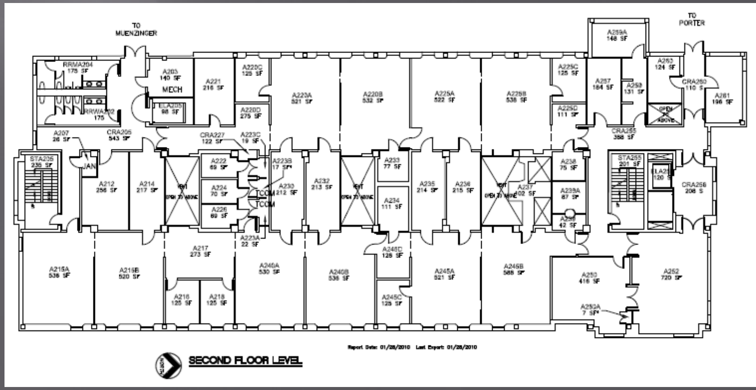
MCDB – “Las Vegas” Laboratory Pilot Study

Labs21 – September 2011

MCDB Building Description

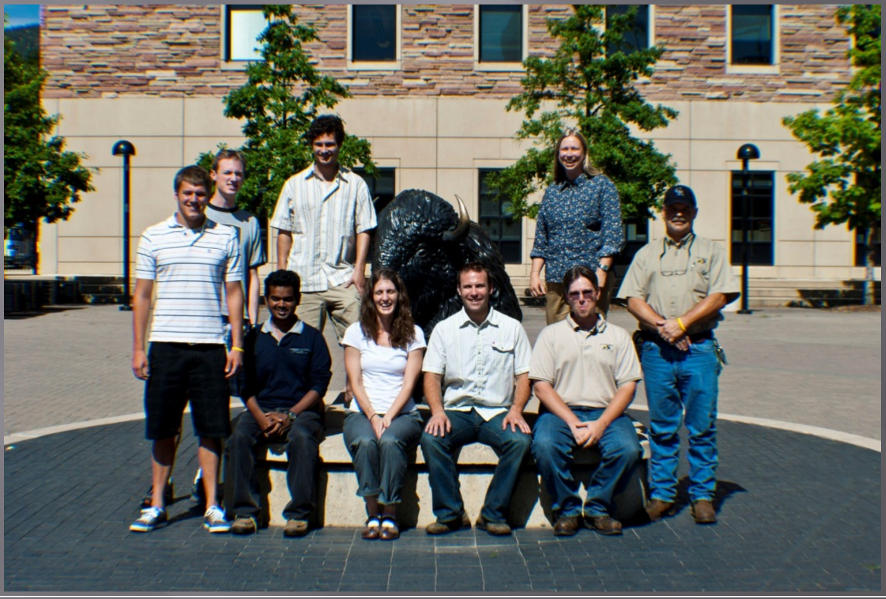
MCDB: 5 story; 137,000 sq. ft.; circa 1995.

- Energy consumption: 18 Btuh/square foot , 51 kWh/square foot
- ACH ranged 10 - 64 ACH.
- Indoor Air Quality (IAQ) issues
- HVAC system, VAV with reheat, heat from central campus steam, cooling chiller plant for MCDB
- *Utility rates for the campus = $0.10/kWh & $16/1000 lbs of steam*



MCDB Building Description (cont.)

- Building rebalanced based on loads.
  - UCB HVAC technicians rebalanced the system, re-programmed the boxes and repair/replaced as needed.
- EH&S then performed the acetone test in a area of the lab based on the before and after air change rates.



Results

- IAQ issues were eliminated

- The % of annual energy consumption reduced for the building is ~38% for both heating and cooling. (eQuest energy model)
- Annual energy savings were estimated to be $60,00 for steam and electricity usage, project costs estimated to be $125,000.* A simple payback is estimated to be 2 years. (Measurement and Verification are confirming results this year.)

Conclusions

- UCB AHJ's and EH&S were able to:
  - Establish a comfort level in lab safety based on a performance ACH (which is often reduced) from:
    - Code and standards review
    - Spill risk analysis
    - Load, hood and hazard comparison
    - Lab safety protocol
    - Pilot study and testing – confirming the assumptions in the load and hazard analysis.
  - Develop a pragmatic approach that could be applied campus wide while maintaining lab form, fit and function.

Questions and Considerations

1. How do we continually fine tune the assumptions in load verification and hazard analysis ?
    - Additional monitoring with different compounds and varying volumes to fine tune the models
    - 2-Zone Model showing generation and decay in near and far field
    - Continuous IAQ monitoring
2. How do we quantify energy savings?
    - UCB estimates an average of 15-19% energy reduction for the entire campus
    - Measurement and verification to accurately determine the energy savings vs. projected savings needed but how do we do this with a moving benchmark
3. How do we effectively manage lab spaces on campus which are constantly changing and evolving?
    - Collaboration with lab users to lower effective ACH based on lab use and activity
    - Required to update EH&S and Facilities Management when changes to lab use are made

Contact Information

Shannon Horn, P.E. , AHJ, LEED A.P.
Shannon.Horn-1@colorado.edu

Timothy Lockhart CIH, CHMM
Timothy.Lockhart@colorado.edu

University of Colorado Boulder

RESOURCES AND SUPPORTING DOCUMENTATION

"Technical Guidance For Hazards Analysis", U.S, EPA and U.S. FEMA, December 1987 [Equation (7), Section G-2, Appendix G. Available at http://www.epa.gov/OEM/docs/chem/tech.pdf

"Risk Management Program Guidance For Offsite Consequence Analysis", U.S. EPA publication EPA-550-B-99-009, April 1999. [Equation (D-1), Section D.2.3, and Equation (D-7), Section D.6, Appendix D. Available at http://www.epa.gov/emergencies/docs/chem/oca-all.pdf]

http://www.air-dispersion.com/msource.html#Non-Boiling

"IH Mod" American Industrial Hygiene Association, Exposure assessment Strategies committee http://www.aiha.org/insideaiha/volunteergroups/Pages/EASC.aspx

December 11, 2008

Proposed Agenda:

Intent: To Determine and come to a consensus on acceptable Minimum Air Change Rate and/or CFM/sq ft. for Laboratories for New and Existing Buildings across campus:

1. Drivers effecting ACH (Health and Safety, and energy consumption)
    a. Codes
        i. IBC B occupancy or H occupancy for laboratories (B occupancy does not stipulate a lower limit, H does)
        ii. IFC (B occupancy no stipulation, H has lower limit requirements)
        iii. IMC ventilation based on cfm/sq. ft and type of space and pollutant generation.
    b. Adopted Standards guidelines (How are we using these on campus as adopted standards or guidelines.)
        ✓ i. NFPA 45 2003, (4 unoccupied., 8 occupied)
        ✓ ii. NIH building requirements not known, needs to be investigated further
        iii. ASHRAE Laboratory Design guide -2001 (4 to 12 ACH, performance based on containment)
        iv. OSHA – 29 CFR Part 1910.1450 (4 to 12 ACH)
        ✓ v. ACGIH, 24 ed. Wide range (Does EH&S have these standards)
        ✓ vi. ANSI/AIHA Z9.5-2003 Wide range (Does EH&S have these standards)
    c. Industry Standards: Engineered Solutions, CFD modeling, contaminant detection.
    d. Other drivers based on EH&S, UCB Fire Marshal and UCB mechanical Engineering not mentioned above, i.e. ACH calculations based on 10 ft high ceilings vs total volume.
2. Determine which of the above we will be enforcing, using as a guideline or other approach.

3. Conclusion provided Labs are B occupancy the AHJ + EH+S base ACH in labs ~~on and~~ based on performace + type of research.

Occupational Exposure Limits Reviewed

- OSHA PEL – 1,000 ppm
- ACGIH TLV – 500 ppm (NIC -200)
- STEL – 750 ppm (NIC-500)
- NIOSH REL – 250 ppm

Time weighted Average

- IDLH – 2,500 ppm
- LEL – 25,000 ppm

Lessons learned and Recommendations

- Altering sample locations
- Measuring “dead spots” of airflow
- Smaller volumes of material
- Not in trays…directly on floor (or similar)
- DON’T DISTURB THE ACETONE!
- Each Building System needs to be evaluated with the above approach.
- Team approach was instrumental in the implementation of the project, high caliber students, BAS technicians, LWEEP program, and lab users cooperation.

Pros and Cons of Modeling

Pros

- Cost effective
- Adjustable for multiple compounds
- Easily altered variables

Cons

- Overly Conservative
- Based on Assumptions
- Doesn't account for:
  - laboratory layout
  - Airflow patterns
  - "dead zones" or areas of limited airflow
  - Room thermals

Pros and Cons of Monitoring

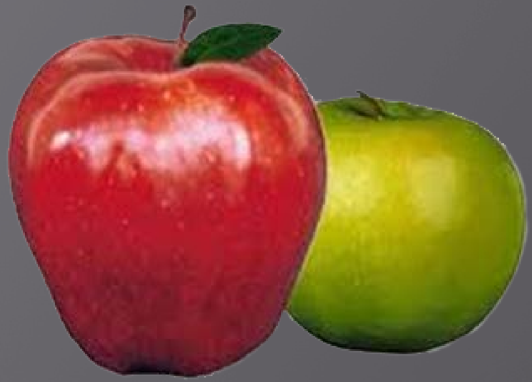
Pros

- Real life scenario
- Laboratory specific
- Actual air concentrations shown over time

Cons

- Expensive
- Based on assumptions
- Individual compounds
- Can't extrapolate to other areas
- Hard to conduct and obtain lab space to conduct to tests

Consistency between Assumptions and Variables (Modeling & Monitoring)



Variables

- Temperature and Pressure
- Room Volume
- Airflow Rates
- Dimensions and geometry of spill (length, width, depth)
- Chemical Properties (i.e. VP, MW, SG)
- Air exchange Rates
- Evaporation Rate
- Even mixing

Assumptions

- Wind Speed over spill (0.09 m/s for 4 ACH and 0.254 m/s for 19 ACH)
- 0 ppm Acetone in supply air and background of laboratory
- Even mixing in lab
- Spill is on the floor of a laboratory
- Hazardous chemicals would be used in a hood or with LEV