Green Labs Symposium

Smart Labs Workshop
Boston | March 27, 2014

Your Presenters

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Today’s Agenda

• Welcome and Introductions
• Introduction to Smart Labs
• Prerequisites for Smart Labs
• Lighting
• Mechanical System
• Determining the Potential for Air Change Reductions
• Centralized Demand Controlled Ventilation
• ANSI Z9.5 2012
• Exhaust Stack Discharge Volume Reduction
• Dashboard and Energy Savings
• Constant Commissioning and Return on Investment
• Conclusion and Wrap-Up
• Questions and Answers

What is a “Smart Lab”

• “Smart Labs” are newly constructed or retrofitted laboratories that reduce building system energy consumption by 50% or more, augment established safety protocols and designs, and provide a data stream effectively commissioning the building at all times.
Smart Lab Evolution

- UC Irvine’s Smart Labs Initiative includes multiple features that were piloted and verified before campuswide deployment.

- Making the deep energy cuts that are required to meet a 50% savings goal requires that theories be tested, perceptions changed, and results evaluated.

Retrofitting or New Construction

With the exception of the building shell, all Smart Labs retrofits can be completed in occupied buildings with minimal lab interruptions.

- Service interruptions are directed in the contract for duration, timing, and notification that must be given
- Scope of work may or may not include temporary supply and exhaust fans
- Contractors must work with air flowing (both supply and exhaust) with all shutdowns minimized even when this increases the number of steps or amount of work
- Town hall meetings prior to construction with building occupants
- Posted construction schedules in hallways and email updates
- 2-week in-person notice given to each individual lab
Where did we start?

<table>
<thead>
<tr>
<th>Laboratory Building</th>
<th>BEFORE Smart Lab Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Type</td>
</tr>
<tr>
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<td>P</td>
</tr>
<tr>
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<td>Engineering Hall</td>
<td>E</td>
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<td>Averages</td>
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</table>

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

- All of these are existing buildings
- Multiple types of science represented
- Starting air change rates often higher than we expected
- Mix of mechanical system designs
- Most buildings were already very efficient.

Why are the savings possible?

- Supply fan
- Exhaust fan
- Chiller
- Boiler
- Pump
- Lights

- 8760 hours
- Don’t discount the synergistic savings

- Bring outside air in
  1. Preheat or Cool OSA
  2. Filter OSA
  3. Pressurize OSA

- Reheat added to bring SAT up keeping lab from getting too cold

- Exhaust Air
  1. High Velocity
  2. Often Add makeup air from the roof

- Spaces over-illuminated and poorly controlled
Returns on a Wide Range of Energy Prices

Energy Savings Are Not Linear!

For a 100HP Supply fan, reduced 10% provides a 27.1% HP savings

\[ HP2 = HP1 \left( \frac{RPM2}{RPM1} \right)^3 \]

\[ HP2 = 100 \left( \frac{90}{100} \right)^3 \]

177,097 kWh per year

Green Labs Symposium March 27, 2014
Engaging the Campus

Town Hall Meeting
• Explain the Why, What, When, How
• Answer Questions, provide documentation
• Partnership opportunities, help us help you

Pre-construction Meeting
• Provide schedule
• Provide contacts
• Provide solutions to concerns raised in town hall

Post-construction Follow Up
• Show what changed
• Follow up on post construction issues
• Provide training on dashboards, data, and results

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Prerequisites of a Smart Lab

1. Constant air volume (CAV) to variable air volume (VAV)
2. Pneumatic to direct digital control
3. Individual exhaust to manifoldsed exhaust
4. Differential pressure control for pumps
5. Thermostat location and other existing challenges

Variable | Constant Air Volume
A design that is misunderstood

- Ventilation Rate (CFM)
  - Variable: VAV CFM
  - Constant: CAV CFM

Savings
High Air Change Rates Can Erase Energy Savings

- No HVAC demand for cooling
- Sash raised FHEV opens, GEX closes
- Sash closed FHEV closes, GEX opens
- SAV never changes
- System is VAV but performs as CAV

Typical Lab Prior to Retrofit
Typical Lab Post-Retrofit

Research Laboratory

- Variable volume control valves
- Mixing boxes for temperature control and control valves for flow control

Dual Duct to Control Valve Connection for Lab Supply Air and Proper Setup

- Duct static pressure must be equal to prevent backflow
- Temperature control of supply air
- Control of flow (CFM) of supply air
Pneumatic Control to Direct Digital Control

- Do not require frequent calibration
- Can perform complex sequences
- Can receive instructions from a master computer
- Can transmit to a master computer information such as damper position, room temperature, supply air quantity, and supply air temperature

Manifolded Exhaust

N+1 Exhaust Fans connected to a common plenum

- Premium efficient motors
- Variable frequency drives installed
- Control based on static pressure of the exhaust duct responding to increase or decrease in demand
- Redundancy for increased safety and no lab downtime during service
Constant Flow to Variable Flow

For maximum energy savings, reliability, and turn down, convert building heating water systems to variable volume.
- Add Variable Frequency drives to the pumps.
- Replace 3-way valves with Pressure Independent Control Valves (PIC-V)
  - Valve leakage wastes energy. Do not just close the bypass the best practice is to replace the valve.
- Check each VAV box for valve leakage, replacement of 2-way valves may be necessary. Leak-by is a significant energy waste.
- Install differential pressure monitoring and reset schedule

Fixing the Known

If you have known issues in your lab, you need to address them now or as part of the retrofit. Smart Lab retrofits can resolve your deferred maintenance nightmare.

- Failed lab air control valves
- Occupant installed snorkels, ductwork taps, other interesting “improvements”
- Static pressure sensors that are failed or need recommissioning
- Stuck dampers
- Broken actuators
- Dirty duct work
- Over-ridden VFDs
Location, Location, Location

Heat-generating equipment placed next to thermostats wastes energy.

Monitoring and Verification Capabilities

1. What level of metering do you have?
2. What level of metering do you need?
3. Where is the information you need?
4. What metrics should I trend and make decisions with?
Look Closer ... Find More Savings

At the zone level, measurement and verification resolution are so high that you are essentially constantly commissioning the building.

Building Management System
Cost-Effective Submetering

**Meter Specs**
- 12 - 24 channels per board
- Meter accuracy +/- 0.5% (0.25% typical)
- V, I, active energy, reactive energy, power factor

**Current Transformer Specs**
- Sensor accuracy +/- 1%
- Current transformers 60 - 400 amps
- Clamp-on installation

ESP Touch Pro Installation

- Flexible and split core CTs
- Non-Invasive
- No Power Down Required (Typ.)
Visualization of Lab Energy Use

Demand Drill Down
Baselines

1, 15 Minute Baselines (10 in 10)

Metrics That Can Lead to Action

LEED® ENERGY STAR® Labs 21 Benchmarks

Total Building Load

Lighting

HVAC

Plug Load

Information that is actionable
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Lighting

• Lighting should be as flexible as possible.

• Provide task lighting when additional illumination is needed.

• Encourage occupants to be conscious of their lighting needs.

• Do not discount the synergistic savings from eliminating heat produced by over-illuminated spaces.
What Is Your Lighting Power Density?

LPD = (Watts / Area) x Occupancy Sensor x Circuiting Strategy x Day lighting

Lab Area LPD from 1.1 to 0.6
Lab Prep LPD from 1.0 to 0.4
Prep Room LPD from 2.0 to 1.0
Corridor LPD from 0.6 to 0.3

Non Daylighting Areas

32 Watt T8 -> 25 Watt T8
NLO Ballast .87-.90 BF -> RLO Ballast .71 BF

This retrofit on a 4 lamp fixture, on 4380 hours a year, saves 170 kWh per year.
UC Irvine retrofitted ~15,000 fixtures campuswide, saving 2,550,000 kWh per year!
We had ZERO complaints!
**Automatic Daylighting Controls**

Lab areas within 15 feet of windows and all private offices and conference rooms are equipped with automatic daylighting controls.

**Daylighting Without the Glare**

Light Louver Window Blind

Perforated window blinds

Light Shelves
**Sequence**

Auto on to 50%  →  Manual on to 100%  →  Auto off

**Lighting**

Lighting is controlled per lab bay -- not per lab -- to maximize savings.
Lighting

Lighting is controlled per lab bay -- not per lab -- to maximize savings.

LED Task Lighting

Magnetically mounted LED task lighting
Bi-Level Lighting in Stairwells and Corridors

Corridor lighting is often on all year, 24 hours a day, and represents a good opportunity for occupancy sensing.

Bi-level lighting in stairwells is another opportunity that should not be overlooked.

Synergistic Effects of Lighting Retrofits

The formula:

\[
\text{Fraction of Lighting Savings as Air Cooling Savings} = \frac{\text{Fraction of the Year of the Cooling Season} \times \text{Lighting Load Met by Mechanical Cooling System’s Coefficient of Performance}}{}
\]

Lighting retrofit reduces watts per square foot

Sensible heat gain of the space is reduced

Cooling load of the space is reduced

Only results in energy savings when lighting load is a contributing factor. High air change rates will eliminate savings!
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Mechanical System

- Maximize occupant comfort
- Minimize air change rates
- Maintain lab safety
- Provide a right-sized system that is both variable and efficient
- Make use of dashboards to review energy consumption and indoor air quality
Mechanical System Balance

Autoclaves
Ultra-low temp freezers
Refrigerators
Incubators
Water purification systems
Microscopes
Computers
Shake tables

Lighting
Occupants
Building shell
Windows

6-10 ACH

High air change rates often exceed all of the lab’s process and operational loads.

Mechanical System Balance

Autoclaves
Ultra-low temp freezers
Refrigerators
Incubators
Water purification systems
Microscopes
Computers
Shake tables

Lighting
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REHEAT

6-10 ACH

Balance to the room is brought about by adding varying amounts of reheat.
Lowering the air change rate with the installation of a CDCV system swings the balance the other way.

Lower air change rates more closely match the natural lab process load, reducing both fan power and reheat.
A Pristine (Unassigned) Lab

Fully Utilized Open Labs
Fully Utilized Open Labs

[Image of a laboratory with equipment and supplies on shelves]

Fully Utilized Open Labs

[Image of another laboratory with similar equipment and supplies]
Fully Utilized Open Labs

Support Labs and High-Density Zones

Support Labs
• Bio Safety Cabinets / dry lab
• Microscope rooms
• Specialized equipment spaces

High Density Zones
• Cold Storage, ULT and Refrigeration
• Incubators
Normalized Electrical Demand by Zone

- Equipment Halls: 9%
- Interior Lab Spaces: 26%
- Open Lab Spaces: 65%

Designing, and ventilating 100% of the space, for the 9%, is a first cost and life cycle cost that can and should be avoided.

Solutions to dealing with Heat Load

High density zones of heat need to be dealt with. Using dilution ventilation is an energy waste.

- Autoclaves
- Ultra-low temperature freezers
- Refrigerators
- Incubators
- Water purification systems
- Microscopes
- Computers
- Shake tables

What is a solution to high density zones?
Dealing with the heat is the only way to reduce air change rates. Equipment corridors with slot exhaust grills are located on each floor to reduce lab heat gain.

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Laboratory is a “Mechanical System”  
Safety & Effective Contaminant Control

All HVAC elements in balance and maintained

- Fume hood commissioning & placement
- Effective air supply and air exhaust locations
- Good air mixing to avoid contaminant build-up & achieve effective dilution
Evaluate Air Mixing & Air Quality

- UCI Investigative Protocol – drafted
- Lab air mixing & exposure monitoring studies
- Evaluate air flow patterns – helium bubbles

Improved Air Mixing – Fabric Air Diffuser

Less air turbulence to fume hood

Air forced down in front of hoods

Air evenly distributed into space
Types of Contaminant Control

1. Primary control – Local exhaust ventilation (at source of contaminant generation)
2. Secondary control – Dilution of room air (ACH)

Primary (Source) Control – Fume Hood
Primary (Source) Control - Snorkel

Primary (Source) Control - Glove Box
Air Changes per Hour (ACH)  
(secondary control – dilution ventilation)

- Explored the opportunity to safely reduce ACH
- Lab buildings at 6+ ACH
- Reduce to 4 ACH occupied?
- Reduce to 2 ACH unoccupied with occupancy sensing?

Moving From 6+ ACH -> 4/2ACH  
A Process Over Time

- Balance energy savings & safety
- Labs21 (now I2SL) Conferences
- Industrial Hygiene/Engineering consultant
- Technology that facilitates this reduction
- Energy team discussion & evolution
Question: Is Increased ACH Safer?

“Specification of Airflow Rates in Laboratories” by Tom Smith, Exposure Control Technologies, Conclusions:

- ACH as a metric for dilution is “too simplistic”
- Must consider other factors that lead to exposure, (i.e. contaminant generation rate, air mixing, etc.)
- “Increased airflow [may increase] contaminant generation and distribution throughout the space”
- May lead to “false sense of safety”

Answer: Not Necessarily

Alternatives to simply increasing ACH:

- Base air exchange rate on contaminant generation
- Review lab practices, especially outside fume hood
- Attain proper air mix ratios
- Reduce overall ACH to save energy and increase ACH as needed via “smart controls"
Table: Codes on Air Changes

<table>
<thead>
<tr>
<th>Agency</th>
<th>Ventilation Rate</th>
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<tbody>
<tr>
<td>OSHA 29 CFR Part 1910.1450</td>
<td>4-12 ACH</td>
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<tr>
<td>ASHRAE Lab Guides</td>
<td>4-12 ACH</td>
</tr>
<tr>
<td>Universal Building Codes – 1997 (UBC)</td>
<td>1 cfm/ft²</td>
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<tr>
<td>International Building Code – 2003 (IBC)</td>
<td>1 cfm/ft²</td>
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<tr>
<td>International Mechanical Code – 2003 (IMC)</td>
<td>1 cfm/ft²</td>
</tr>
<tr>
<td>United States Environmental Protection Agency (U.S. EPA)</td>
<td>4 ACH Unoccupied Lab 8 ACH Occupied Lab</td>
</tr>
<tr>
<td>American Institute of Architects (AIA)</td>
<td>4-12 ACH</td>
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<tr>
<td>National Fire Protection Association 45-2004 (NFPA)</td>
<td>4 ACH Unoccupied Lab 8 ACH Occupied Lab</td>
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<td>Nuclear Regulatory Commission Prudent Practices</td>
<td>4-12 ACH</td>
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<tr>
<td>ANSI/AIHA Z9.5</td>
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<tr>
<td>ACGIH 24&lt;sup&gt;th&lt;/sup&gt; Edition, 2001</td>
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Standard states that ACH is not an appropriate concept for designing containment control systems. The specific room ventilation rate should be established by the owner. The required ventilation depends on the generation rate and toxicity of the contaminant and not the size of the room in which it occurs.

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**Determining the Potential for Safe Air Change Reductions**

Lab bench top risk assessments

- Answers question “can air changes be safely reduced?”
- Helps determine air change rate
- 2 full time industrial hygiene staff (1 funded by utility savings)
High or Low Hazard Lab?

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High or Low Hazard Lab?

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High or Low Hazard Lab?

Lab Bench Top
Risk Assessment Process

Step 1 - Conduct room-by-room hazard screening

- Industrial hygienist evaluates worker exposure
- Review chemicals inventory/operations
- Interview lab staff
- Review engineering controls
- Focus is outside of fume hood
Lab Bench Top Assessment Process

- Compare risk assessment results with hazard criteria
- Enter assessment results into database
  - If follow-up needed, no ACH reduction
  - If no follow-up needed, reduce ACH

Risk Assessment Criteria

High-risk labs – no ventilation reduction
  - Biosafety Level 3 (airborne biohazard)
  - Highly toxic gases
  - Special ventilation requirements
  - Chemicals/operations identified as high risk by bench top assessment or follow-up exposure monitoring
  - Fire area control limits exceeded
Risk Assessment Criteria

• Chemicals of Concern
  – Acutely toxic by inhalation
  – Asphyxiants
  – Anesthetic gases
  – Carcinogens
  – Reproductive toxins
  – Air contaminants that have occupational exposure limits (OELs, PELs, TLVs)
  – Strong odor producers

Risk Assessment Criteria

Fire Concern (physical hazard)

– Flammables/pyrophorics - amounts stored over fire control area limits
– 6 ACH at all times
– Reduce amounts!
Risk Assessment Criteria

Animal Allergen Concern

Airborne Allergens (proteins) from animal dander
- No exposure limits for allergens
- 6+ ACH at all times in 24/7 animal areas

The most allergenic animals are:
- Mice
- Rats
- Guinea pigs

Step 2 – Industrial Hygiene Follow-Up

Post Initial Risk Assessment

• Follow-up for chemicals of concern
  - Lab staff exposure monitoring studies
  - Work with lab staff to improve work practices
Step 2 – Industrial Hygiene Follow-Up

After follow-up for chemicals of concern
– Ventilation reduction possible if exposures can be controlled (improved work practices)
– ACH may be increased until work practices are improved
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1. Room sensor mounted in general exhaust duct samples a packet of air
2. Packet of air is routed to the sensor suite
3. Sensors measure indoor air quality
4. Information Management System determines need for increased ventilation, commands VAV controllers, and serves data to a web server.
5. System monitoring is available via a web based interface.
CDCV System Architecture

Supply Air Duct
Lab Room 101
Lab Room 102
Classroom 103
Room Sampling Port

Supply Air Reference Probe

GEX Duct Probe (typ.)

Sensor Suite with TVOC, CO₂, dew point & particulate sensors

Vacuum Pump

Air Data Router

Web Based User Interface

Server

Sensor Suite

Structured Cable

Vacuum Pump

Air Data Router

Duct Probe
CDCV - Sensors

<table>
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<th>Sensors</th>
<th>Activation Range</th>
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Smart Labs - Added Features

UC Irvine seeks to continuously update the lab air control system with safety and energy saving features.

Safety
- Red Buttons
- Lab display unit (LDU)

Energy Savings
- Occupancy sensors
Red Buttons

**Red Button** – In the event of a chemical spill or other event requiring increased ventilation in a lab, an emergency ventilation override button has been installed. Pressing this button will increase air change rates to maximum while maintaining negative lab pressurization.

Lab Display Units

- Programmed to display ACH, occupancy status and ventilation offset information
- Provide real-time feedback
Smart Lab “Safety Net”

Occupant Training
Describes Smart Lab features

Air Changes per Hour (ACH)
(secondary control – dilution ventilation)

• 6+ ACH → 4 ACH occupied/2 ACH unoccupied with occupancy sensing
• CDCV senses chemical and increases ACH
• Sensor failure must “fail safe” to 6+ ACH
  — Sensor suite does not detect all chemicals
  — Changed out every 6 months
• Visual signal to occupant of ACH
• Emergency exhaust red button
CDCV and Risk – Challenges

- Lack of “universal” CDCV sensor for all chemicals
- Sensors location and time delay to react
- Changes in research operations and staff
- Incomplete chemical inventories
- Great variety of hazardous operations and chemicals

Risk Assessment – Next Steps

- Developed system to identify changes in lab operations
- Re-assess bench top operations:
  - New researchers arrive
  - Lab moves (notification!)
  - Periodic reassessments

- Promote current/complete chemical inventories
  Lowered ACH is not “sustainable” without EH&S risk assessments and management of change!
Lab ACH Reductions

Based on Risk Assessments Results to Date

- 13 lab buildings
- 660 lab rooms & 1,840 work processes assessed
- 530 lab rooms - reduced ACH (~80%)
- 130 lab rooms - not reduced ACH (~20%)

Risk Assessment Conclusions

- Energy savings can be achieved without compromising safety
- Lab ACH determination requires:
  - Flexibility (evolving process)
  - Contaminant source control
  - Active EH&S involvement in risk assessment of lab operations with lab staff
  - Reassessment when lab changes occur
Investigative Protocol
Optimizing Airflow and Air Monitoring Strategy
Purpose and Scope

• Verify our risk assessments!

1. Evaluate and optimize laboratory ventilation airflow and air mixing
   – Helium bubble simulation to qualitatively evaluate air mixing

2. Evaluate and document that occupational exposure limits at 4 and 6 ACH are not exceeded.
   – Air monitoring for contaminants

Helium Bubble Simulation
Investigative Protocol
Optimizing Airflow and Air Monitoring Strategy

Air Monitoring

- Quantitative evaluation of air change rates
  - Quantify degree of air mixing
  - Correlate chemical exposure monitoring results to air mixing
  - Tracer gas study
  - CFD modeling