Deep Energy Efficiency Strategies for University Buildings

Smart Lab Design, Implementation, and Results

Matt Gudorf
Campus Energy Manager
Environmental and Economic Considerations

- UC Irvine is signatory to the Presidents Climate Action Commitment
- The University of California will design and build all new laboratory buildings to a minimum standard equivalent to a LEED™-NC “Silver” rating.
- The University of California policy for all new building projects, other than acute-care facilities, to outperform the required provisions of the California Energy Code (Title 24) energy-efficiency standards by at least 20 percent. (UC Irvine’s goal is to outperform by 50%)
- First cost vs. lifecycle is not only economic but environmental.
UCI’s Goal is to reduce lab energy consumption by 50%.

- Set Goals & Targets
- Analysis & Development
- Energy Improvement Measures
- Measurement & Verification
- Implement Smart Labs: CDCV, ESDVR, Day Lighting and Lighting Controls, Low Pressure Drop Filters, Remove Duct Noise Attenuators, Static Pressure Reset
- Review data, Labs21 Toolkit, Scope out energy project
- Verify savings and use added tools to constantly commission labs
- Labs Efficiency Cycle
- Set Goals & Targets
<table>
<thead>
<tr>
<th></th>
<th>2001 Best Practice</th>
<th>Gross Hall 2010 Smart Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-handler/filtration airspeeds</td>
<td>400 ft/min. max</td>
<td>350 ft/min. max</td>
</tr>
<tr>
<td>Total system (supply + exhaust) pressure-drop</td>
<td>6 in. w.g.</td>
<td>&lt;5 in. w.g. (incl. dirty filter allow.)</td>
</tr>
<tr>
<td>Duct noise attenuators</td>
<td>Few</td>
<td>None</td>
</tr>
<tr>
<td>Occupied lab air-change/hr. (ACH)</td>
<td>6 ACH</td>
<td>4 ACH w/contaminant sensing</td>
</tr>
<tr>
<td>Night air-change setback (unoccupied)</td>
<td>No setback</td>
<td>2 ACH w/occupancy + contaminant sensing</td>
</tr>
<tr>
<td>Fume hood face-velocities</td>
<td>100 FPM</td>
<td>100 FPM</td>
</tr>
<tr>
<td>Fume hood face-velocities (unoccupied)</td>
<td>100 FPM</td>
<td>60 FPM (Zone Presence Sensors)</td>
</tr>
<tr>
<td>Exhaust stack discharge velocity</td>
<td>~3,500 FPM</td>
<td>~2,100 FPM Wind Tunnel Modeled</td>
</tr>
<tr>
<td>Lab illumination power-density</td>
<td>0.9 watt/SF</td>
<td>0.6 watt/SF w/LED task lighting</td>
</tr>
<tr>
<td>Fixtures near windows on daylight sensors</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy Star freezers &amp; refrigerators</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Out-perform CA Title 24</td>
<td>20-25%</td>
<td>50%</td>
</tr>
</tbody>
</table>
If you can’t see where the energy is going, finding savings will be difficult.

At the zone level, measurement and verification resolution are so high you are essentially constantly commissioning the building.
Cost Effective Sub Metering

**Meter Specs**
- 12 Channels Per Board
- Meter accuracy: +/- 0.5% (0.25% Typ.)
- V, I, Active Energy, Reactive Energy, Power Factor

**Current Transformer Specs**
- Sensor Accuracy: +/- 1%
- CT’s 60-400 Amps
- Clamp on installation
System Description

Acquisition SW
SQL Express DB

Database Server

TCP/IP

Individual 12 Channel Meters

EnerACQ User Interface

Multiple Users

User PC
The building shell will effect every system within the facility

BUILDING ENVELOPE

HVAC System Size

Building Shell

Lighting Requirements

Environmental Impact
BUILDING ENVELOPE

Window Shades

Light Colored Concrete

Shaded entry via setback and overhang elements
R-30 roof insulation

T-24 Cool-roof material
Ultra-high-performance glazing

Light Shelves
BUILDING ENVELOPE

Landscape belts at building perimeters reducing heat and reflection impacts

Drought tolerant vegetation using minimal reclaimed water
LIGHTING

1. Lighting should be as flexible as the possible
2. Provide task lighting when additional illumination is needed
3. Encourage occupants to be conscious of their lighting needs
4. Do not discount the synergistic savings of heat produced by over illuminated spaces
Perforated Window Blinds
Make use of daylighting without the glare
LIGHTING

Lab areas within 15’ of the window line and all private offices and conference rooms are equipped with automatic daylighting controls.
Lighting is controlled per lab bay, not per lab to maximize savings.
LED Task Lighting

Magnetically mounted LED Task Lighting
Mechanical System

1. Maximize occupant comfort
2. Minimize air change rates
3. Maintain lab safety
4. Provide a right sized system that is both variable and efficient
5. Make use of dashboards to review energy consumption and indoor air quality
Operable Windows are interlocked with the HVAC system.
Operable Windows Interlocked with HVAC System

When the window opens the supply diffuser is closed
Centralized Demand Controlled Ventilation

1. Monitors the indoor air quality of multiple zones through a network of structured cables and air data routers
2. Analyzes the sampled air with a battery of sensors
3. Provides the lab air control system with an input for increased ventilation when necessary.
4. The system is only an input to your lab air control system, no different than a thermostat, or sash position sensor.

Minimum of 4 air changes per hour in occupied labs
Minimum of 2 air changes per hour in un-occupied labs
CDCV System
Dashboard and Data Trends for each zone:

- Air Change Rates
- IAQ
- Sash position of each fume hood
- Occupancy
- Relative Humidity
- Temperature
- Total Supply
- Total Exhaust
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.
Added Features

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

Safety
- Red Buttons
- LDU (Lab display unit)

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. This button should **not** be pressed in the event of a fire!
Currently in use at Gross Hall

- Programmed to display ACH, occupancy status, and ventilation offset information within the lab
- Provide real-time feedback to lab occupants

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Change Rate</td>
<td>4.0 ACH</td>
</tr>
<tr>
<td>Occupancy</td>
<td>OCCUPIED</td>
</tr>
<tr>
<td>Room Offset</td>
<td>-208 cfm</td>
</tr>
</tbody>
</table>
Visualization of lab HVAC use
Monitoring Fume Hood Usage

- Fume hood usage range
- This hood shows usage between 0% open and 65% open.
- Change in average sash position from the month prior
  Red indicates poorer average green indicates improved average sash management
Smart Labs are not just controls and sensors.

Smart Labs provide real time feedback as well as monthly reporting data that is actionable.

Return on investment is directly affected by lab practices.

How many hoods are in use right now in your lab and how far open are the sashes?
Total flow & ACH profile for six day period

Total Flow & ACH
All labs, Sunday to Saturday

ACH
CFM
Total Flow & ACH
All labs, Sunday to Saturday

Total Supply
Total ACH
Air Change Rates for Room 1200
Graphed over 6 days

Typical Lab flow profile
Single Lab, Sunday to Saturday

ACH

RM 1200B RM 1200 ACH
The delta between 6 air changes per hour of previous labs designs and the 4/2 ACH of Gross Hall is yielding ~$58,000 per year in energy savings.
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
- Attain proper air mix ratios
- Reduce overall ACH to save energy and increase ACH as needed via “smart controls”
Risk Assessment of Bench Top Processes to Ensure Safety in Smart Labs

- Energy savings can be achieved without compromising safety
- Lab ACH determination requires:
  - Active EH&S involvement in bench top risk assessment of lab operations with lab staff
  - Contaminant source control
  - Reassessment when lab changes occur
  - Current/complete chemical inventories
  - **Flexibility** (evolving process)
Bench Top Risk Assessment Process

- Conduct room by room hazard screening
  - Industrial hygienist (IH) evaluates worker exposure
  - Review chemicals inventory/operations
  - Interview lab staff
  - Review engineering controls
  - Follow Up
Lab Bench Top Risk Assessment- based ACH Decision Tree (qualitative)
Other Considerations

**Good practice:**
- Control contaminants at the “source”
- Don’t rely only on general dilution for control
- Review lab operations/chemicals
- Communication with lab staff

**ACH & exposure:**
- Exposure limits are not based on ACH
- No known correlation between ACH and exposure or disease
There must be a plan to deal with the heat!
Equipment corridors with slot exhaust grills are located on each floor to reduce lab heat gain.
Right Sized Air Handlers & Exhaust
Low velocity air handling units – 350 fpm face velocity

- Increased duct size
- Low pressure drop filters
- NEMA premium efficiency motors
Low velocity exhaust ductwork

Low pressure drop laboratory air system design
Low velocity air distribution system
Low velocity exhaust ductwork

Increased duct size
Wind Tunnel Testing
Challenge Conservative Assumptions
1. Detailed modeling in a wind tunnel to determine the minimum exhaust velocity required as opposed to standard practice

2. BMS configuration running 1, 2, or all 3 fans with a goal of 0% bypass

Resulted in a 27% Fan Power Savings
Lab Exhaust Diagram Animated

- Wind
- Exhaust Fan
- Bypass Damper
- Plenum
- Fume Hood
- Re-Entrainment of Contaminated Air
- Balcony
- Supply Fan Duct
Wind Tunnel Testing
Typical Timeline of Exit Velocity Requirements

- Typical Design
- 1% Design
- Required by Dispersion
- Required by High Air Change Rate
- Required by Low Air Change Rate

Time

CFM x 1000
Wind Tunnel Testing

- Build model of campus
Wind Tunnel Testing

- Build model of campus
- Install model stacks
Wind Tunnel Testing

- Build model of campus
- Install model stacks
- Install air sampling points ("receptors")
Hewitt Hall vs. Gross Hall

Designed in 2001

- Exceeded Title 24 by 23.7%
- Biomedical research
- Lighting upgrade in 2009
- Exhaust Stack Discharge Velocity Reduction in 2009
- Re-Commissioned in 2010
- 76,905 Square Feet

Designed in 2009

- Exceeded Title 24 by 50.4%
- Biomedical Research
- Submitted to USGBC for LEED Platinum certification
- 94,705 Square Feet
Gross Hall’s Lab Utilization Is Nearly Twice Hewitt Hall’s

Percent Occupied by Building (7 days)

Gross Hall: 58%
Hewitt Hall: 27%
Building Load Per Square Foot

Watts / Gross Square Foot

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Watts per Square Foot</th>
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<tbody>
<tr>
<td>0:15</td>
<td>1.00</td>
</tr>
<tr>
<td>1:00</td>
<td>2.00</td>
</tr>
<tr>
<td>1:45</td>
<td>3.00</td>
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<tr>
<td>2:30</td>
<td>4.00</td>
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<tr>
<td>3:15</td>
<td>5.00</td>
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<tr>
<td>4:00</td>
<td>6.00</td>
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<tr>
<td>4:45</td>
<td>5.50</td>
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<tr>
<td>5:30</td>
<td>5.00</td>
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<td>6:15</td>
<td>4.50</td>
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<td>9:15</td>
<td>2.50</td>
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<td>1.50</td>
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<tr>
<td>11:30</td>
<td>1.00</td>
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<tr>
<td>12:15</td>
<td>0.50</td>
</tr>
<tr>
<td>13:00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Hewitt Hall

Gross Hall
## Lighting

<table>
<thead>
<tr>
<th>Previous Best Practice</th>
<th>Space Type</th>
<th>Gross Hall</th>
</tr>
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<tbody>
<tr>
<td>0.9 watts/sqft</td>
<td>Offices</td>
<td>0.49 watts/sqft</td>
</tr>
<tr>
<td>1.1 watts/sqft</td>
<td>Labs</td>
<td>0.66 watts/sqft</td>
</tr>
<tr>
<td>1 watts/sqft</td>
<td>Overall Conditioned Space</td>
<td>0.61 watts/sqft</td>
</tr>
</tbody>
</table>

### 24 Hour Demand Curves

- **Hewitt Hall 2nd Floor Lighting Demand**
- **Gross Hall 2nd Floor Lighting Demand**

### 24 Hour Actual Watts Per SQFT

- **Hewitt Hall Watts Per Sqft**
- **Gross Hall Watts Per Sqft**
It is easy to see how campus labs compare to each other but what about across the country? [http://labs21benchmarking.lbl.gov/CompareData.php](http://labs21benchmarking.lbl.gov/CompareData.php)
Adding Hewitt and Gross Halls

- Hewitt is right at the average
- Gross Hall beats the most efficient lab benchmarked by 18%
The HVAC savings of 1 CFM/ft² at $4-5 per CFM can reduce operational significantly.

A 1 CFM reduction at Hewitt Hall in just the open lab bays would reduce operational cost by $83,250 per year.
AHU + EF + Pumps + Chilled Water = Building Square Feet

Watts per Square foot

- Hewitt Hall
- Gross Hall
- Gross Total Building
- Hewitt Hall Total Building
Chilled Water Use

BTU/h Per Square Foot

Hewitt Hall

Gross Hall
Comparing 2 Similar Floors

Hewitt Hall vs. Gross Hall
2nd Floor
**Lab Air Supply and Exhaust**

**Hewitt Hall 2nd Floor**
- 6 Air changes per hour minimum
- No set back during unoccupied periods
- Zone presence sensors on fume hoods

**Gross Hall 2nd Floor**
- 4 Air changes per hour minimum occupied
- 2 Air Changes per hour minimum unoccupied
- Zone presence sensors on fume hoods
- Centralized Demand Controlled Ventilation system adjusting ACH for indoor air quality.
Air change rates are dynamic responding to occupancy, IAQ, sash position, and thermal demands.

Lab 2501 averages 8 air changes per hour.

Lab 2200 averages 4 air changes per hour.

Evidence of where the buildings HVAC energy savings are achieved.
Continuous Commissioning

- Meaningful Analysis and Reports
- Actionable information
- Verification of Actions Taken Physical and Behavioral

**CDCV**
- Find failed lab air control valves
- Review of fume hood sash management
- Ensure safe lab air quality
- Find excessive air flows due to point sources of heat

**Sub Metering**
- Monitoring of fans, pumps, and lighting control systems
- Verification of energy retrofits
- Reduce demand charges by modifying operations

**BMS**
- Locate simultaneous heating and cooling
- Reset of static pressure to minimum required
- Control run times of office areas
HDP1 is a distribution board on the 1st Floor. It is responsible for feeding several equipment loads, autoclave units EQ2, EQ3, and EQ4. HDP1 is fed directly from the main switchboard at 480/277 volts. The board maximum current rating is 225 amps. The largest load on HDP1 is the medium autoclave EQ2, which is rated at 75kVA.

Zone level resolution can lead to peak demand savings

Autoclave In Gross Hall

![Graph showing peak demand history for GH HDP1]

60 kW peak

<table>
<thead>
<tr>
<th>Panel Name</th>
<th>Floor</th>
<th>Parent Panel</th>
<th>MSB Circuit</th>
<th>Voltage</th>
<th>Configuration</th>
<th>VA (A)</th>
<th>VA (B)</th>
<th>VA (C)</th>
<th>VA Detail</th>
<th>I(A)</th>
<th>% of Panel</th>
<th>% Measured</th>
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</thead>
<tbody>
<tr>
<td>EQ2</td>
<td>1</td>
<td>HDP1</td>
<td>HDP1</td>
<td>480</td>
<td>Wye</td>
<td>24,942</td>
<td>24,942</td>
<td>24,942</td>
<td>74,825</td>
<td>90</td>
<td>58.4%</td>
<td>100%</td>
</tr>
<tr>
<td>EQ4</td>
<td>1</td>
<td>HDP1</td>
<td>HDP1</td>
<td>480</td>
<td>Wye</td>
<td>10,254</td>
<td>10,254</td>
<td>10,254</td>
<td>30,761</td>
<td>37</td>
<td>24.0%</td>
<td>100%</td>
</tr>
<tr>
<td>EQ3</td>
<td>1</td>
<td>HDP1</td>
<td>HDP1</td>
<td>480</td>
<td>Wye</td>
<td>7,482</td>
<td>7,482</td>
<td>7,482</td>
<td>22,447</td>
<td>27</td>
<td>17.5%</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>42,678</td>
<td>42,678</td>
<td>42,678</td>
<td>128,033</td>
<td>154</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Zone level resolution can lead to peak demand savings

Gross Hall average site demand ranges from a baseline of 148kW to an average peak of 205 kW

Did running the Autoclave on peak just cost you $600 in demand charges?
Troubleshooting a CO2 leak with the CDCV System

Researcher connects 4 tanks of CO2 to the lab distribution system and within 8 hours they are empty.

To find the leak the research staff could have spent hours soaping lines and connections and wasting additional gas listening for the leak.
Suspected location of CO2 leak

CO2 Graph for client "UCI" and building "Gross Hall"
The PI then plotted the room with the suspected CO2 leak:

It was quickly located and repaired.
The Knowledge Center has been used to locate lab equipment placed too close or under thermostats.
Return on Investment

Commissioning

- Cx, Rx, MBCx is approximately $2 per SqFt
- Hewitt Hall MBCx $131,309
- Net present value for 10 years (MBCx every 5 years)
  Hewitt Hall $113,590

Cumulative Cash Flow MBCx Project

MBCx

MBCx Cumulative Cash Flow  MBCx Net Savings
Return on Investment

Sub metering and monitoring your lab can be very competitive with the cost of a single commissioning effort.

- CDCV ~$3.12 per SqFt
- Sub metering $0.20 per SqFt
- Hewitt Hall Sub Metering and CDCV $302,888
- Net present value for Hewitt Hall continuous commissioning (10 years) $665,903

Cumulative Cash Flow

![Cumulative Cash Flow Chart](chart.png)
Return on Investment

Smart CCx although a larger initial investment provides for greater long term savings as well as strategic analysis, monitoring, and savings that can not be accomplished with traditional MBCx.
The Smart Lab developed at UCI has many individual features that UC Irvine has piloted over the last three years before being incorporated into Gross Hall.

In order to make the deep energy cuts that are required to meet a 50% savings goal, theories must be tested, perceptions changed and results evaluated.
WATER CONSERVATION MEASURES

Stormwater runoff control
Drought tolerant landscape selection
Reclaimed irrigation water
Water conserving plumbing fixtures
Ultra-low flush Urinals
Dual-flush Toilets
As you may be aware, Gross Hall is one of the most energy-efficient lab buildings in the United States. Please take a moment to review these unique features.

**Centralized Demand Controlled Ventilation** – The Am zostać system installed in Gross Hall research laboratory spaces, monitors indoor air quality and adjusts supply and exhaust air delivery based upon indoor contaminant levels. The automated system samples packets of air and then analyzes them with a battery of sensors to determine air change rates required for each zone. The sensors are calibrated every six months and the system is monitored via a web interface.

**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. This button should **not** be pressed in the event of a fire.

**Occupancy Controlled HVAC** – The Smart Lab design of the ventilation system includes occupancy based air change rate controls. Occupancy sensors will allow for air change rate reductions during unoccupied periods. The system does not affect fume hood ventilation. Upon initial entry after a long period of inactivity, the lab may feel stuffy, please allow a few minutes for the room to normalize.

**Lab Ventilation Display Unit** – The display panel located on the wall of each lab allows occupants to check the status of the lab’s air change rate, as well as ensure that the occupancy sensors are working properly. Please note that the panels are labeled Phoenix Controls Corporation and have a 3” x 3” LCD screen. Air change rates should remain at approximately 4 air changes per hour (ACH) when the lab is occupied and 2 ACH when unoccupied.

**Operable Windows** – Gross Hall has been equipped with operable windows in offices and conference rooms. The heating and air-conditioning system is interlocked with the operation of the windows. Therefore, opening a window will turn off mechanical ventilation to that zone.

**Occupancy Controlled Lighting** – After manually turning on the lights with a light switch, the overhead lights will automatically turn off during unoccupied periods. Overhead lighting may also be turned off manually. We encourage everyone to turn off all lights whenever they leave the laboratory for an extended period.

**Natural Interior Lighting/Automatic Overhead Lighting Reduction** – The Gross Hall is designed to maximize interior illumination via natural lighting. In addition, the overhead interior lights are connected to photosensors that control the intensity of the interior lighting based upon the availability of outdoor light.

**Fenlite LED Task Lighting** – Task lighting will be provided to users who require additional lab bench top lighting. To receive task lighting, please contact Customer Service Representative Sherry Long at 824-6221.

**Energy Efficient Filtration/Better Indoor Air Quality** – Gross Hall is equipped with energy saving high efficiency Merv 14 particulate filters. The result: lower energy costs and improved indoor air quality.

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**Smart Lab “Safety Net”**

- **Occupant Training**
- **Occupant welcome brochure**
- **“Red Button” signage**

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**ROOM AIR PURGE SYSTEM**

Press button in the event of chemical spill or release. After activation, leave the building and call 911.

**DO NOT ACTIVATE FOR A FIRE**
Maintenance

- Mechanical Repairs to more complex systems
- Software updates/adjustments to BMS Controls
- Sensor calibration/replacement of CDCV system
- Calibration of sash sensors, zone presence sensors, etc.
Questions?