Smart Labs Initiative

UCI University of California, Irvine

Smart Laboratories Cut Energy Consumption More Than Half

A U.S. Department of Energy Better Buildings Challenge Demonstration Project

Why target laboratories?

Research universities have large carbon footprints because laboratories are energy-intensive, typically constituting two-thirds of the utilities consumed by such institutions. Therefore, reducing laboratory energy consumption is the primary way to shrink the carbon footprint of a research university. Until recently, most attempts to improve laboratory energy efficiency had plateaued at 20-25 percent better than code. UCI set the savings goal much higher – ***50 percent!*** – challenging established best practices and, if successful, raising the performance bar for all laboratories. We also set a binding requirement that these savings could not be achieved at the expense of safety.

Why do laboratories consume so much energy?

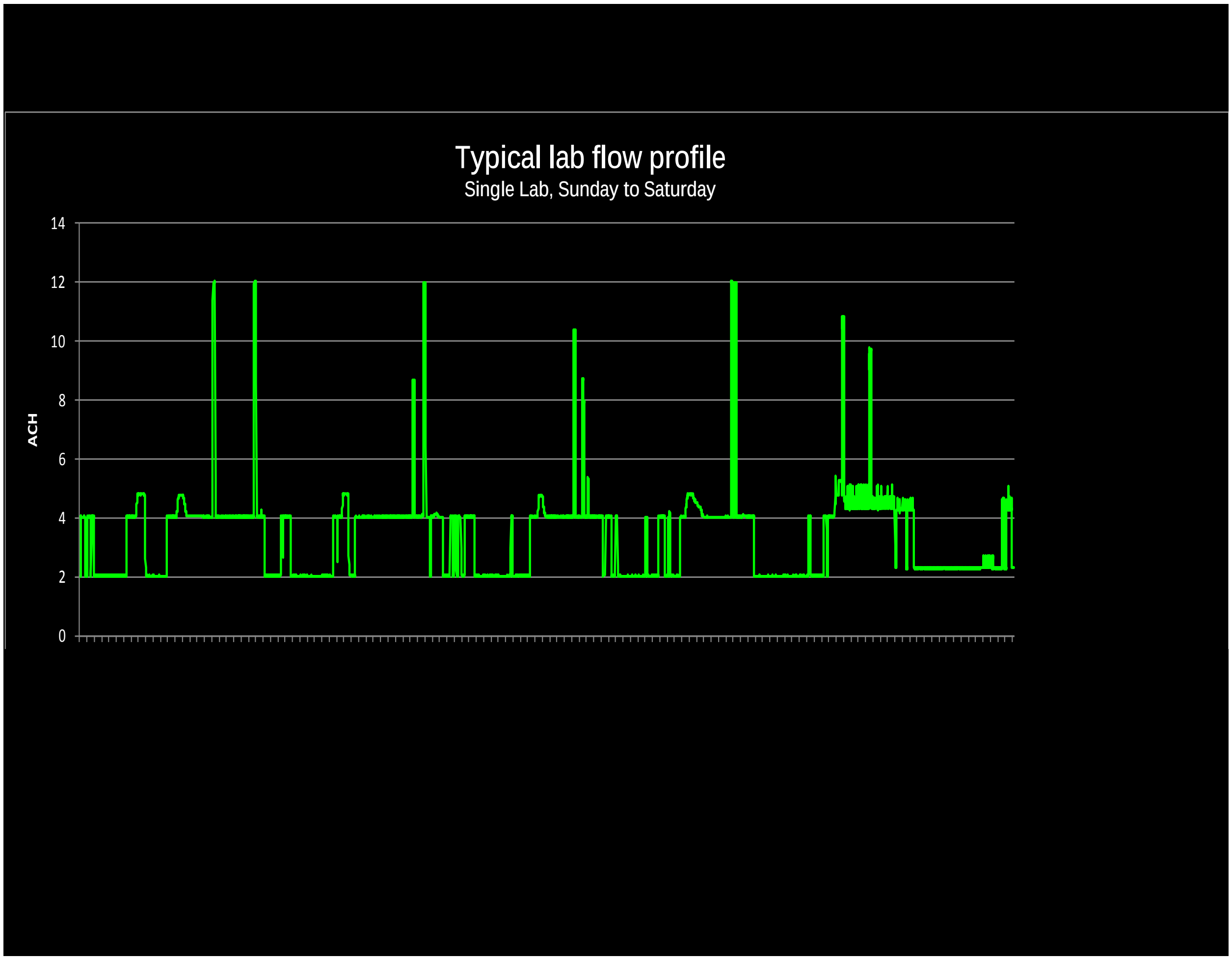
Laboratory buildings use 100 percent outside air ventilation, with no recirculation of return air. Thus, the entire internal air volume of a typical lab building is exhausted to the atmosphere via high-power exhaust fans through high-velocity exhaust stacks every 5-8 minutes. An enormous amount of energy is required to supply, heat, cool, humidify, dehumidify, filter, distribute, and exhaust this air, and this process takes place 24/7, ***whether the laboratory is fully occupied, partially occupied, or vacant***. This key parameter is known as air changes per hour (ACH). Many laboratories in U.S. universities, colleges, and private sector and governmental research facilities use 10 or more ACH.

Smart Labs Concept

In 2008, UCI facilities/energy engineers recognized that recently constructed laboratories possess the unexploited potential to be far more efficient without compromising occupant safety if variable air volume (VAV) features and digital controls could be integrated with advanced air quality and occupancy sensors driving smarter control logic. The end goal of this concept is to deliver appropriate ACH based on measured conditions of air quality and occupancy, on a space-by-space basis. This concept was pilot-tested as UCI's Smart Labs Initiative, an integrated set of laboratory design criteria and performance standards, including:

- real-time air quality sensing that adjusts ACH in response to certain contaminants;
- reduced fan, filtration, and duct airspeeds below prior best practice standards;
- 50-70 percent less exhaust fan energy by enabling reduced stack discharge airspeeds;
- reduced internal heat loads to enable lower ACH feasibility (e.g., low illumination power density, daylighting sensors, ENERGY STAR equipment and exhaust grilles directly above heat-discharging equipment);
- reduced thermal inputs during setback periods;
- chemical hygiene safety assessments in laboratories; and a
- preventive maintenance program for Smart Lab HVAC components/systems.

The combined effects of all these features, integrated holistically into a smart lab, can cut non-process energy use ***in half***. Such a facility senses air quality as well as occupancy and varies ventilation rates on a zone-by-zone basis – from two ACH unoccupied, to four ACH under normal occupied conditions, and peaking to maximum ACH when it detects threshold levels of particulates, volatile organic compounds, or CO_2. The chart below displays this dynamic control of air changes for a typical smart lab zone:



A smart lab creates a rich "information layer" by delivering air quality data to users; by texting technical staff whenever a zone triggers high ACH; and by providing a detailed, zone-specific record of air quality and system performance. Thus, a smart lab with these essential features provides a safety net of information such as ongoing air quality monitoring and responsive adjustment of ACH not previously available. (A few laboratories, such as biocontainment facilities, employ selected smart lab features on a case-by-case basis.) Although a smart lab includes many sensors and controls that require sophisticated maintenance, these same features provide self-diagnostics that enable ongoing monitoring, maintenance, and performance. The features summarized above were applied in UCI's first "smart lab" project completed in 2010 (see next page):

Sue & Bill Gross Stem Cell Research Laboratory

- Applies a comprehensive, integrated set of energy design parameters (see page 5)
- Adjusts ventilation (ACH) to respond to real-time air quality and occupancy
- Outperforms California's Title 24 building energy standards (similar to ASHRAE 90.1) by 50.4 percent

The following table displays the design parameters applied to the Sue & Bill Gross Stem Cell Research Laboratory and shows how these criteria were upgraded compared to recent laboratory designs at UCI:

Smart Lab Energy Design Parameters

Parameters/Features	Recent Best Practice	Smart Lab
Air handler/filtration airspeeds	400 feet/min max	300 ft./min max
Total system (supply + exhaust) pressure drop	- 6 in.w.g.	< 5 in.w.g.
Duct noise attenuators	Few	None
Occupied lab air-changes/hr. (ACH)	6 ACH	4 ACH w/contaminant sensing
Unoccupied air-change setback	No setback	2 ACH with contaminant sensing + reduced thermal inputs while building "coasts" during setback
Maximum ACH	8-10 ACH based on cooling load	10-12 ACH when contaminants sensed
Low-flow, high-performance fume hoods and/or automatic sash closers	No	Yes, where hood density warrants
Exhaust stack discharge velocity	~ 3,000 FPM	No fixed standard, building-by-building analysis typically ~1,500 FPM > 1,500 FPM if/when necessary To avoid re-entrainment
Lab illumination power density	~ 0.9 watt/SF	< 0.6 watt/SF with LED task lighting where needed
Fixtures near windows on daylight sensors	No	Yes
ENERGY STAR freezers and refrigerators	Some	Most
Outperform California Title 24 energy efficiency standards	25%	> 50%

Smart Lab Features Can Be Retrofitted Into Most Existing Laboratories

While the capital investment for a smart lab retrofit is sizable (since building controls and many features of ventilation, exhaust, and lighting systems are essentially re-engineered), the energy savings are substantial. ***Seven key steps*** constitute a smart lab retrofit. All seven steps are necessary to attain savings or 50 percent or greater:

1. A successful retrofit project must start from a fundamental platform of direct digital controls, variable air volume, manifolded exhaust fans, differential pressure control of heating hot water (three-way valves converted to two-way valves, installed pressure sensors and variable frequency drive), and known problems fixed. If needed, installation of these baseline features would constitute "phase 1," providing the foundation for a full smart lab retrofit.

2. Real-time, demand-based ventilation controls ACH based on occupancy and measured air quality. As noted in the Smart Labs Energy Design Parameters Table on Page 5, zone-by-zone ACH varies from two ACH unoccupied to 10-12 ACH when threshold levels of volatile organic compounds (VOCs), particulates, or carbon dioxide (CO_2) are detected. (Carbon monoxide sensing is added as needed.)

3. Laboratory lighting efficiency is improved and associated heat load is reduced, thus *enabling* fewer air changes.

4. Exhaust fan energy is sharply reduced:
   a. An exhaust dispersion study is performed.
   b. Based on dispersion study, exhaust stack discharge airspeeds reduced by:
      1) closing bypass dampers, and/or
      2) extending stack heights (typically 4-8 feet), and/or
      3) running manifolded fans in parallel
   c. If dispersion study indicates re-entrainment problems under specific wind conditions, exhaust stack discharge airspeed may be anemometer-controlled.

5. Because lower fan speeds and duct airspeeds reduce HVAC noise significantly, duct noise attenuators are removed, where feasible. Attenuators are often found upstream of exhaust fans and both upstream and downstream of supply fans. Sometimes it is feasible to remove resistive elements from them while leaving their exterior casings intact. If resultant noise is higher than acceptable, duct liner can be installed with a minor energy penalty compared to that of a typical duct attenuator.

6. Fume hood standby ventilation is reduced to conform to the new AIHA/ANSIZ9.5 standard. Following a hazard evaluation, qualifying hoods may be reduced from approximately 375 internal air changes per hour to 200-250 air changes per hour.

7. Final commissioning to ensure that all improvements are working, integrated, and meeting performance specifications – including information technology functions inherent in the "information layer." Initial commissioning may be required prior to steps 1or 2 (above) if there is uncertainty about existing system conditions and what needs to be included in the retrofit program.

Why do smart lab retrofits save so much energy?

Most smart lab retrofits have yielded savings beyond our saving goal. There are three primary reasons for this:

1. We found that many laboratories were actually operating with higher air changes than designed or required by code. The average was 8.2 ACH prior to retrofit.

2. Reducing air changes cut reheat almost to zero.

3. The retrofit process uncovered many known, and some unknown, system issues and malfunctioning parts. Thus, smart lab projects funded a multitude of deferred maintenance problems and design deficiencies through the project's energy savings.

Although most UCI smart lab retrofit projects have yielded savings *greater than 50 percent*, this was *not* because these buildings were inefficient prior to retrofit, as displayed on the summary table below:

Summary of Smart Lab Retrofit Results

Laboratory Buildings		Before Smart Lab Retrofit			After Smart Lab Retrofit		
Name	**Type***	**Estimated Average ACH**	**VAV or CV**	**Was more efficient than code?**	**kWh Savings**	**Therm Savings**	**Total Savings**
Biological Sciences 3	B	9.0	VAV	~ 30%	45%	81%	53%
Calit2	E	6.0	VAV	~ 20%	46%	78%	58%
Croul Hall	P	6.6	VAV	~ 20%	40%	40%	40%
Engineering Hall	E	8.0	VAV	~ 30%	59%	78%	69%
Gillespie Neurosciences	M	6.8	CV	~ 20%	58%	81%	70%
Hewitt Hall	M	8.7	VAV	~ 20%	58%	77%	62%
McGaugh Hall	B	9.4	CV	No	57%	66%	59%
Natural Sciences 2	P, B	9.1	VAV	~ 20%	48%	62%	50%
Reines Hall	P	11.3	CV	No	67%	77%	69%
Sprague Hall	M	7.2	VAV	~ 20%	71%	83%	75%
Averages		**8.2**	**VAV**	**~ 20%**	**57%**	**72%**	**61%**
* Key: P = physical sciences, B = biological sciences, E = engineering, M = medical sciences.							

The investment required for a smart lab retrofit, albeit substantial – and the payback period, 6-8 years at California energy prices and UCI's typical prior ACHS – yield very high efficiency and energy savings. However, the savings extend beyond energy efficiency. As noted earlier, a number of deferred maintenance problems are addressed (and funded) by a smart labs retrofit project. And the "information layer" provides building and energy managers with real-time performance data that should eliminate the expense of periodic recommissioning.

Finally, because smart lab features provide more data to assist with decision making than do prior ventilation practices, a safer lab environment may be achieved. Rather than put faith in a particular, fixed air change rate, a smart lab provides data on real-time, *measured* air quality for certain contaminants, for which a zone-by-zone historical log is created. And the energy savings are so substantial that a slice of the savings is sequestered for additional laboratory safety assessment. Although the phrase is overused, this truly does represent a “new paradesign” for laboratory safety.

Summary of Smart Lab Costs and Benefits

Costs

- Debt service for capital investment in smart labs retrofit project (or capital increment for new construction)
- Ongoing, periodic costs of recalibrating Aircuity sensors
- An increment of targeted funding for chemical hygiene assessments and advanced HVAC and electrician support to ensure ongoing system performance

Benefits

- Energy savings – mainly a function of local energy prices, prior ACH, and local climate (which will affect the ratio of electric to thermal savings)
- A number of malfunctioning components and deferred maintenance problems are uncovered and corrected by a comprehensive smart lab retrofit.
- The expense of periodic building recommissioning can be avoided if the “information layer” provides real-time performance feedback.
- As energy prices increase over the long life of a smart labs retrofit investment, considerable cost-avoidance will accrue.
- Essentially all moving parts in a smart lab’s supply and exhaust systems are slowed down, with resultant reduction in wear and maintenance. Component lifespans are expected to increase well in excess of motor and airspeed reductions.

UCI is committed to creating safe, smart, and sustainable environments and communicating our results and “lessons learned” via webinars and through presentations at the International Institute for Sustainable Laboratories (I^2SL, formerly Labs 21), California’s Higher Education Sustainability Conference, the Big Ten Environmental Stewardship Group, and numerous other professional meetings. Most new and retrofitted laboratories can cut energy consumption and carbon emissions 50 percent or more by applying the integrated ensemble of smart labs design criteria. The campus welcomes visitors who want to see first-hand this Better Buildings Challenge showcase project.

Frequently Asked Questions

Do all laboratories qualify for smart labs retrofit?

No. Prior to installing and activating reduced air-changes a laboratory undergoes an assessment by an industrial hygiene/lab safety specialist. See: http://www.ehs.uci.edu/programs/energy/BenchtopProcessUC-CSULabHVACworkshop.pdf
Biosafety Level 3 and 4 labs are highly regulated and therefore exempted from smart lab retrofits, as are laboratories where airborne contaminants not sensed by the current Aircuity sensor suite may be present. At UCI, 15 percent of laboratories have been exempted from smart lab retrofits.

What if lab operations change?

We have lab managers and EH&S facility managers who are in the labs frequently. If major changes take place, we are confident that we will be notified. However, we do not rely on this notification completely. We rely on proper lab training, proper chemical handling and storage procedures, and point-source containment of emissions. In the event of a fugitive emission, we then have room ventilation of 4 ACH per hour, indoor air monitoring response, and HVAC override buttons that can be activated. Dilution ventilation is not a metric for safety. Rather, proper lab design and safe procedures provide optimal protection of workers.

What if the lab uses a chemical not sensed?

Not all chemicals, vapors, or gases are sensed. This is addressed by the laboratory bench top assessment process cited above.

How often are sensors changed?

Every six months.

What if a sensor drifts within the six-month period?

The sensor does not use a fixed reference point to determine the need for increased air changes in the room. The system takes a sample of supply air and compares it to the lab zone sample. The delta between the supply and lab is then calculated, and air change rates are increased as the delta increases. If there is sensor drift, the reference point and the sample point drift together because they originate from the same sensor.

How do you justify the cost of the sensor changes?

Our experience indicates that the cost of sensor change-out is roughly 10 percent of the energy savings.

What if our energy costs differ from California prices?

Three factors will drive whether a smart labs retrofit will pay for itself in another institution, in a different locale:

1. Relative energy prices, particularly for electricity.
2. Existing lab ACH (which may be considerably higher than UCI's prior lab air-changes).
3. Most locales will experience far greater thermal savings than UCI realized in its temperate climate.

Thus, even if your electricity costs, say, 40 percent less than UCI's power, your institution may realize equivalent (or even greater) savings if your average ACHs are higher and/or your environment has more degree-days of heating and cooling.

How do you ensure that smart lab performance does not degrade?

When UCI started the Smart Labs program, the key to maintaining the energy savings was the information layer that was created. Monitoring more data, across more systems, with less human intervention is the only way to ensure that our investment is maintained. The number of points that can be monitored and trended over time grows exponentially with the granularity and range over which the lab building can operate. Utilization of the information layer to maintain savings for a single building can be achieved by monitoring the discrete systems' graphical interfaces. UCI has determined that at some point monitoring all of the discrete systems is not possible as the amount of data is simply overwhelming. In order to ensure that performance does not degrade, the information being generated by each system is now being tagged and collected in a single database, and an analytic engine identifies issues worthy of attention, such as failed economizers, simultaneous heating and cooling, leaking or stuck valves, operation during unoccupied hours, failure to release points in operator override, and poor fume hood sash management.

Is there evidence that exposure events in smart labs are less frequent, more frequent, or unchanged compared to labs where air-changes have not been adjusted?

During our lab risk assessment process in smart labs, Environmental Health and Safety has identified hazardous processes (potential exposure events) and has provided input to reduce the hazard. These recommendations have been implemented, resulting in fewer potential exposure events. Additionally, we have completed 72 industrial hygiene air sampling events in smart labs. All the measurements have been within allowable occupational exposure limits except for one. Utilizing local exhaust ventilation, we were able to reduce the one exceedance to permissible levels. By performing chemical exposure monitoring and staying aware of lab activities through periodic lab assessments, our Environmental Health and Safety group has shown that it is possible to maintain lab workers' exposure levels to hazardous substances at very low levels by implementing proper engineering control measures. From our evaluation, potential exposure to hazardous materials in smart labs is as safe as in non-smart labs.

In terms of financial and operational risks, is a Smart Lab retrofit a risky project, or not?

Smart Labs are not risk-free as the systems that are being installed are designed to be as dynamic as possible. The increased range of lighting, heating, cooling, and exhaust are all subject to failure, with safety being paramount. When systems do fail, they are designed to fail “safely,” and this results in some energy waste. Mitigation of this risk can be accomplished with automated fault-detection software, a staff that is trained to respond to increasingly complex systems, and a workplace culture that reports energy and maintenance issues as a top priority.

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