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Smart Laboratories Cut Energy Consumption More Than Half *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. UC Irvine 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?

The short answer is ventilation. 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-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 24x7, ***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 ten or more ACH.

Smart Lab Concept

In 2008, UC Irvine 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 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 reduce the ACH when conditions permit, on a space-by-space basis. This concept was pilot-tested in UC Irvine's Smart Labs Project, an integrated set of laboratory design criteria and performance standards, including:

- real-time air quality sensing;
- reduced fan, filtration, and duct airspeeds below prior best practice standards;
- 50-70 percent less exhaust fan energy by reducing stack discharge airspeeds;
- reduced internal heat load to enable lower ACH feasibility (e.g., low illumination power density, daylighting sensors, Energy Star equipment, and exhaust grilles directly above heat-discharging equipment); and
- reduced thermal inputs during setback periods.

The combined effects of all of 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 CO₂. The following chart displays this dynamic control of air-changes for a typical smart lab zone:



A smart lab creates a rich “information layer,” making the working environment safer by providing 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 is significantly safer than prior designs. (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 UC Irvine’s first “smart lab” project, completed in 2010:



Sue & Bill Gross Stem Cell Laboratory

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

The following table displays the design parameters applied to the Sue and Bill Gross Stem Cell laboratory, and shows how these criteria were upgraded compared to recent laboratory designs at UC Irvine:

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Smart Lab Energy Design Parameters		
Parameters/Features	Recent Best Practice	Smart Lab
Air-handler/filtration airspeeds	400 ft/min. max	350 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 w/contaminant sensing + reduced thermal inputs while building “coasts” during setback
Maximum ACH	8-10 ACH based on cooling load	10-12 ACH when contaminants are 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 Typical~1,500 FPM >1,500 FPM if/when necessary to avoid re-entrainment
Lab illumination power-density	~ .9 watt/SF	< .6 watt/SF w/LED task lighting where needed
Fixtures near windows on daylight sensors	No	Yes
Energy Star freezers & refrigerators	Some	Most
Out-perform CA Title 24	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 get essentially re-engineered), the energy savings are substantial. *Seven key steps* constitute a smart lab retrofit. All seven steps are necessary in order to attain savings of 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 (3-way valves converted to 2-way valves, installed pressure sensors and VFD), 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 Lab Energy Design Parameters Table (above), zone-by-zone ACH varies from 2 ACH unoccupied to 10-12 ACH when threshold levels of VOCs, CO₂, particulates, or CO₂ are detected. (Carbon monoxide sensing is added as needed.)
3. Laboratory lighting efficiency is improved and associated heat load is reduced, thus *enabling* lower 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 internal air-changes per hour.
7. Final commissioning to ensure that all improvements are working, integrated, and meeting performance specifications -- including the IT functions inherent in the "information layer." Initial commissioning may also be required prior to steps 1 or 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 savings goal. Three reasons:

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 UC Irvine 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 following summary table:

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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
Croul Hall	P	6.6	VAV	~ 20%	48%	62%	50%
McGaugh Hall	B	9.4	CV	no	57%	66%	59%
Reines Hall	P	11.3	CV	no	67%	77%	69%
Natural Sciences 2	P, B	9.1	VAV	~ 20%	48%	62%	50%
Biological Sciences 3	B	9.0	VAV	~ 30%	45%	81%	53%
CALIT2	E	6.0	VAV	~ 20%	46%	78%	58%
Gillespie Neurosciences	M	6.8	CV	~ 20%	58%	81%	70%
Sprague Hall	M	7.2	VAV	~ 20%	71%	83%	75%
Hewitt Hall	M	8.7	VAV	~ 20%	58%	77%	62%
Engineering 3	E	8.0	VAV	~ 30%	59%	78%	69%
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 UC Irvine’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 real-time performance data that should eliminate the expense of periodic recommissioning.

Finally, we believe that smart labs are safer than prior ventilation practices. Rather than put faith in a particular, fixed air-change rate, a smart lab provides data on real-time, *measured* air quality, 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 Aircurity 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.

UC Irvine is committed to creating safe, smart, and sustainable environments and communicating our results and “lessons learned” via webinars and through presentations at Labs21, 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/BenchTopPresentationUCI092011.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 UC Irvine, 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 on the air change rate reduction evaluation flow chart 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 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 UC Irvine realized in its temperate climate.

Thus, even if your electricity costs, say, 40 percent less than UC Irvine'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.

Energy Design Features in Sue & Bill Gross Stem Cell Laboratory

BUILDING ENVELOPE

- Concrete structural frame, high thermal mass (> 12 inches) exposed at exterior walls & internal shear walls
- Light-colored concrete design (reducing heat gain)
- High-performance glazing (Solarban)
- Shaded entry glazing via setback and overhang elements
- T-24 cool-roof surface
- R-30 roof insulation
- Light shelves on south and west exposures
- Landscape belts at building perimeters reducing heat and reflection

LIGHTING

- Dimmable lighting systems for meeting spaces
- Perimeter day-lighting controls
- Occupancy controlled office, laboratory, and fume hood lighting
- LED task lighting
- Efficient lighting power density:
 - Offices – 0.49 watts/SF
 - Labs – 0.66 watts/SF
 - Overall Conditioned Space – 0.61 watts/SF
 - Perforated window blinds for glare-free daylighting from direct sun

ELECTRICAL

- Low power design elevators
- High-efficiency transformers

MECHANICAL SYSTEMS

- “Right-sized” based on realistic plug loads
- VAV laboratory air system
- CDCV aircurity smart-controls for laboratory air systems
- Minimum of 4 air changes per hour in occupied laboratories
- Minimum of 2 air changes per hour in un-occupied laboratories
- Re-heat is practically eliminated by reducing excessive air-flow
- VAV fume hoods
- Low-velocity air handling units – 350 fpm face velocity maximum
- Low pressure-drop laboratory air system design
- Low-velocity air distribution system
- Low-velocity exhaust ductwork
- Rest room occupancy controlled ventilation
- User displays
- Operable office windows with air conditioning interlocks
- NEMA premium-efficiency motors
- Use of variable-speed drives for AHUs, pumps, and lab exhaust fans

WATER CONSERVATION MEASURES

- Stormwater runoff control
- Drought-tolerant landscape materials
- Reclaimed water for irrigation
- Water-conserving plumbing fixtures
 - Ultra-low flush urinals
 - Dual-flush toilets
 - Ultra low-flow faucets w/sensors

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