Commissioning High-Tech Facilities

By Evan Mills, Ph.D.

High-tech facilities have, at times, been passed over in the quest for energy savings, often under the pretense that they "must" already be optimized or that they are mission critical and should not be disturbed. While it is true that these facilities receive a far higher level of quality assurance and optimization in construction and operation than traditional buildings, energy performance *per se* is often not a central focus. Energy-saving opportunities have received more attention in recent years, including successful efforts to commission new and existing buildings.

High-tech facilities include laboratories, data centers, cleanrooms, health care, and specialized research facilities such as particle accelerators. Although these buildings are specialized, they are also pervasive, occurring in:

- Private industry (from semiconductor fabs to hospital operating rooms);
- Educational institutions (from high school to university labs); and
- The public sector (from agricultural research labs to high-energy physics facilities).

Across the United States, high-tech facilities in the private and public sector have been estimated to spend upwards of $10 billion per year on energy.[1]

These facilities have a number of common characteristics, including around-the-clock operation, high air-change rates and critical activities and safety requirements that rely on proper indoor environmental control for building performance. In some cases, all of the air is once-through and/or requires dehumidification, with far larger volumes of air needing treatment than in conventional buildings. Together these requirements translate into particularly high energy intensities, and correspondingly large opportunities for energy savings. (For more on the energy efficiency potential in these facilities, see http://hightech.lbl.gov.)[2]

About the Author

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	Existing Buildings				New Buildings			Total	
	Number of Buildings	Floor Area (ft^2)	Median Energy Savings	Median Payback (Years)	Number of Buildings	Floor Area (ft^2)	Median Payback (Years)	Number of Buildings	Floor Area (ft^2)
Cleanrooms	0	–			1	301,000	0.1	1	301,000
Data Center	2	12,888	23%	0.5	0	–		2	12,888
Laboratory	50	4,561,593	14%	0.5	18	1,965,065	2.8	68	6,526,658
Healthcare: Inpatient	17	6,791,029	15%	0.6	9	687,959	3.1	26	7,478,988
Healthcare: Outpatient	14	4,319,124	10%	0.1	4	206,300	0.6	18	4,525,424
Total	83	15,684,634			32	3,160,324		115	18,844,957

Note: Percentage savings and payback times not available for all sites.

Table 1: High-tech facilities in the compilation.

While many of the types of deficiencies identified in the commissioning of high-tech facilities can appear in ordinary buildings, the cost—in terms of excessive energy use—is far, far higher. Some technical issues and opportunities are unique to these facilities, as are some of the barriers. Because these facilities are highly mission-critical, the non-energy benefits related to factors such as safety, equipment life, and reliability, which are often associated with energy related commissioning, can be very substantial.

A number of articles and reports address commissioning in high-tech facilities, although many are not focused on energy issues and, indeed, many make no mention whatsoever of energy.[3,4] However, some energy specific resources do exist, such as the Labs21 guide to commissioning existing laboratories for energy efficiency,[5] which, for example, cites the special importance of fume hoods and specialty pressure- or volume-controlled HVAC systems used for safety purposes. (A bibliography of readings on commissioning high-tech facilities is available at http://cx.lbl.gov/hightech.html.)

Our database contains a meta-analysis of commissioning in 115 high-tech facilities across the United States (a subset of a larger database of 643 buildings, representing the collected work of 37 commissioning providers), spanning 1.8 million m^2 (19 million ft^2) of floor area (*Table 1*).[6] Percentage energy savings tends to be somewhat higher than other building types in the database, while absolute savings were significantly higher because of initial energy intensities. Payback times were also among the lowest of any building type we evaluated.

Deficiencies and their Solutions

The most widely documented commissioning case studies in high-tech facilities focus on laboratories. As an example of the scores of deficiencies discovered in the construction of a laboratory facility, Pinnix, et al.[7] found that none of the 163 fume hoods had properly installed alarm monitors (a serious safety issue), while many had faulty control devices and/or miscalibrations.

The commissioning of data centers has been treated in only a few publications and reports. One data center[8] had a precomissioning energy intensity of over 9600 $kWh/m^2 \cdot yr$ (900 $kWh/ft^2 \cdot yr$), or almost \$1100/$m^2 \cdot yr$ (\$100/$ft^2 \cdot yr$), which is about 100 times the energy bill of a typical office building. Just the savings ultimately achieved by commissioning this one facility—1860 $kWh/m^2 \cdot yr$ (173 $kWh/ft^2 \cdot yr$)—is 10 times the median *pre*-commissioning energy use for the nonhigh-tech buildings in our database.

Common reasons for inefficient data center energy use are excessive airflows created in "fighting" hotspots, multiple computer room air-conditioning (CRAC) units fighting where one set of units is dehumidifying while another is humidifying, lack of either integrated waterside or airside economizers, bad airflow containment/control, inefficient chiller plant staging and chilled water (CHW) temperature control (no resets).

Few case studies of data center commissioning have been published. Findings from a data center at the National Oceanic and Atmospheric Administration (NOAA) weather forecasting office in Jacksonville, Fla.,[9] are indicative of other problems that can otherwise go undetected in these types of facilities:

- No balancing dampers were installed to the branch ductwork, making it impossible to balance the system to improve hot/cold spots.
- Some of the electric duct heater serving zones were significantly oversized.
- Condenser coils were corroded and needed replacement (coils were not coated for high salt content atmosphere).
- The condensing units had incorrect head pressure control and hot gas bypass connections.
- The exhaust fan was only producing 33% of design flows.
- The access door on the air ductwork was removed during an inspection and not reinstalled.
- The fan status controls were not responding to the control system.
- The discharge temperature was controlled off the zone with the lowest setpoint, not the zone with the highest actual temperature, causing many zones to be hot.
- The temperature and humidity sensors were out of calibration.
- The lead-lag operation of the redundant air-handling units (AHUs) was not functioning in a fail-safe manner.
- The control sequence caused unnecessary energy use.
- Many of the electric duct heaters were not staging correctly, due to incorrect wiring.

CASE STUDY

Advanced Light Source

Project Summary

Floor Area 11 019 m^2 (118,573 ft^2)

Commissioning Cost $32,000

System Commissioned Chillers

Energy Savings 45.7% (Weather-Normalized)

Payback Less than One Year (>100% Annualized ROI)

Avoided Capital Cost Chiller replacement downsizing from 450 to 350 tons (1583 kW to 1231 kW): $120,000 (based on $1,200/ton [$336/kW]), i.e., four times the cost of the commissioning project

ALS Facility at Lawrence Berkeley National Laboratory in Berkeley, Calif.

Drivers

Observed simultaneous heating and cooling

Deficiencies Identified Through Commissioning

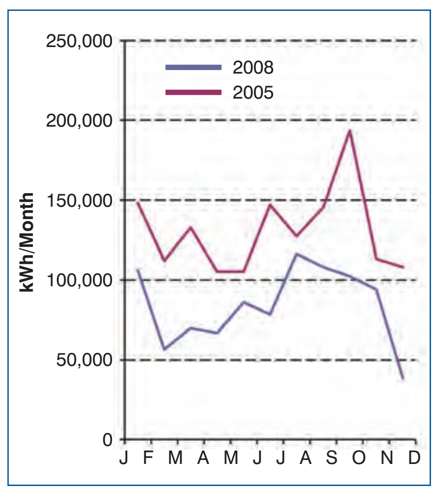
- A false cooling load induced by the facility's temperature-stabilization reheat system.
- The main air-handling units (AHUs), which provide outside air and cooling for the main experimental area, were not functioning properly. Cooling valves in all AHUs were frozen in full-cooling position, causing simultaneous heating and cooling throughout the facility. Outside air dampers not functioning.
- The central plant cooling and heating system's control programming did not optimize energy efficiency performance or equipment longevity.

Measures Implemented Through Commissioning

- Fixed/replaced heating valve controllers and leaking valves; adjusted automated control parameters.
- AHU cooling control valves and dampers repaired.

Outcomes

- **Energy Savings** Chiller plant cooling capacity requirements were reduced by 50 to 70 tons (176 kW to 246 kW) (10%–15%, weather corrected), which corresponded to a 45.7% (weather corrected) reduction in energy use.
- **O&M Improvements** The system was documented, and the staff was trained and became more able to operate the building.
- **Capital Cost Savings** The original chiller plant included a variable speed 1583 kW (450 ton) unit and an old, unreliable 1231 kW (350 ton) unit. The commissioning project lowered chilled water needs so significantly that the 1583 kW (450 ton) chiller went into a "surge" mode of operation that, and if allowed to continue, would damage the chiller. The operators/users believed that a new chiller with an even greater capacity than the 1583 kW unit needed to be installed in place of the old 1231 kW unit. However, due to the energy reductions achieved during the project, a chiller replacement project was completed to install a new variable speed 1231 kW chiller to replace the old 1231 kW unit. The new 1231 kW unit provides the majority of annual chilled water needs, thus becoming the base-load chiller instead of the larger, less efficient 1583 kW unit.



ALS Facility: Chiller electricity use before and after retrocommissioning.

• Cooling load calculations revealed that the requirements were 10% less than the original system design (a reflection at least, in part, of misestimation of internal loads at the time of design).

And, after the preceding items were fixed by a separate contractor, the commissioning authority reinspected and identified the following new issues:

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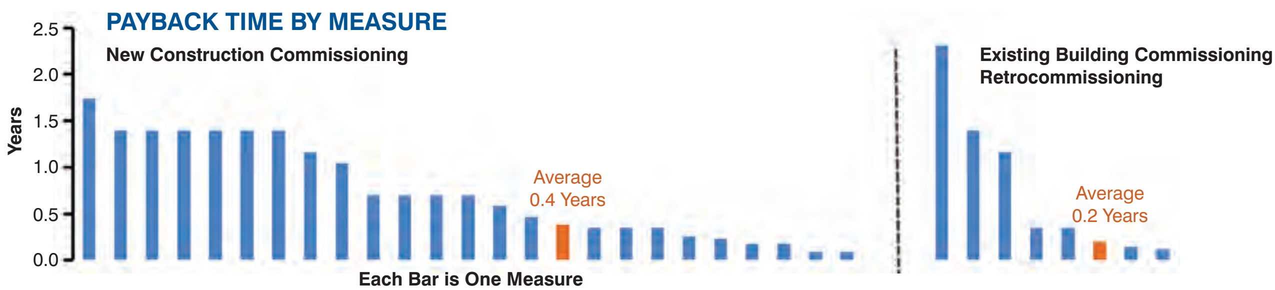
CASE STUDY: TWO TALES OF ONE BUILDING

Molecular Foundry

The Molecular Foundry at Lawrence Berkeley National Laboratory is a 8460 m^2 (91,000 ft^2) high-tech research facility. As is often heard anecdotally, although commissioned during construction, this building was immediately a candidate for another round of commissioning upon completion and occupancy.

During the construction phase, 48 problems were found in the HVAC system and plant, air-handling and distribution, terminal units, and lighting. When commissioning was performed, an additional fourteen deficiencies were discovered and corrected.

Both commissioning phases were highly cost effective, with the new construction commissioning averaging a 0.4 year payback (240% annualized ROI) and the existing building commissioning phase averaging 0.2 years (500% ROI).



	Commissioning–2006 (New Construction)	Retrocommissioning–2006 (Post-Construction)	Total
Measures Implemented To Resolve Problems	Modify controls' sequences of operations. Modify setpoints; and start/stop operation. Calibrate terminal unit damper position feedback. Calibrate lighting occupancy sensors. Bring air-compressor operation into spec.	Replace inefficient, oversize cooling terminal units and perform B.O.S. HVAC upgrades. Eliminate false loading of oversized chiller. Buffer tank modification to optimize return water temperature. Modify air compressor system to reduce need for frequent blowdown.	
Electricity Savings (kWh/year)	441,500	223,200	664,700
Fuel Savings (MBtu/year)	3,840	4,370	8,210
Cost Savings ($/year)*	93,369	77,132	170,501
Commissioning Cost (US$2009)	39,932	16,992	56,924
Simple Payback Time (Years)	0.4	0.2	0.3

*At Standardized National Energy Prices

• OA damper drive motors on two AHUs were not installed properly on the shaft linkage.

• Silicon controlled rectifiers (SCRs) for electric duct heaters on two AHUs were not correctly set up.

• Temperature sensors were not correctly mounted downstream of electric duct heaters.

• The damper jackshaft arm on the outside-air damper on the two AHUs was stripped at the damper connection.

• Direct digital control (DDC) programs for some zones were not responding correctly.

• Specific items in the operator workstation graphics were missing or mislabeled.

• The return air damper for one AHU was broken.

Cleanrooms are another important class of high-tech (and highly energy intensive) facility.[10] Cleanrooms, perhaps more than any other facility type, suffer from a misconception that they are routinely commissioned for energy savings. In fact, they are routinely qualified or certified to ensure that the manufacturing process within will be error free and yield a predictably acceptable product (e.g., semiconductor wafers). However, the qualification process rarely includes energy performance, and in fact, often disregards the energy implications. A cleanroom can be operating "perfectly" in terms of the process and yet use far more energy than necessary. Moreover, there are intense pressures to construct cleanrooms quickly, and there is understandable apprehension about interventions that could compromise the process and product quality.

While attention to the commissioning of cleanrooms (and most other types of spaces) tends to focus on the mechanical systems—including the detection and elimination of co-heating and proper humidification practices—a recent report points out the importance of considering building envelopes. In this case,[11] inspections of the envelope of a cleanroom in the final stages of construction found that 6% of the circulated air was leaking (with hundreds of air changes per hour). Other end uses—such as plug loads or tools—get much less attention.

To our knowledge, quantification of energy focused commissioning in cleanrooms has been offered only once in the open literature: in an important paper and associated presentations by Sellers and Irvine.[12] In that report, a cleanroom was traditionally qualified during construction and all was well. Symptoms began to emerge that the HVAC system was not functioning properly, which led to a series of discoveries and adjustments to the control system. To provide a frame of reference for the prodigious energy use by these types of facilities, electricity consumption of ~100,000 kWh per day and 1,800 therms of natural gas use per day translated to $5,000 per day (at energy prices that are very low by today's standards: $0.039/kWh and $4.4/therm).

Following are some of the problems identified during commissioning this particular cleanroom:

• Key temperature sensors were out of calibration, by nearly 10°F (6°C) in one case.

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• A critical valve was inadvertently not connected to the control system, resulting in excessive heating and extensive simultaneous heating and cooling.

• A preheat coil controller had been set at 110°F (43°C) during a start-up test and associated control sequences were severely sub-optimized.

• The absence of alarms for pre-heat temperatures.

• Presence of frustrating controls and user interfaces that resulted in their being devalued and ignored.

• Air was over-dehumidified in one process, and had to be over-humidified in response to meet space setpoint conditions.

The result of correcting these deficiencies was $60,000 to $80,000 per year in energy savings, at a one-time commissioning cost of $4,700 to $8,000. The corrections also yielded significant safety enhancing benefits, which helped avoid costly future disruptions and potentially costly contamination of the process, resulting in product quality deficiencies.

This project did not have the benefit of a measured baseline and post-commissioning measured savings. An estimate of savings was based on a calculated baseline rooted in an observed operating condition combined with calculated savings based on what engineering principles say will happen after correcting problems identified in the commissioning process. With this in mind, a rough extrapolation of lessons learned to the rest of the facility (not yet completed at the time of the study), suggested annual savings of about $540,000, or about 30% of the facility's entire energy bill, and a payback time of 0.01 years (about four days). As with any case study, these specific results will not necessarily apply to other similar facilities, but the story serves as a clear indication that commissioning in cleanrooms should be taken quite seriously and that further study is merited.

First Cost Savings Can Eclipse Ongoing Energy Savings

An oft-cited non-energy benefit from commissioning—and one of the largest in terms of economic value—is helping to right-size mechanical systems, thereby saving on capital costs during original construction or future retrofit/replacement.

We documented a dramatic example of this in the Advanced Light Source facility at Lawrence Berkeley National Laboratory (sidebar, Page 20) in which huge cost savings were garnered by scaling back a new chiller from more than 450 tons to

350 tons (1583 kW to 1231 kW) (made possible by the energy savings from commissioning). The corresponding onetime capital cost savings were four times the entire commissioning project cost.

Leading commissioning practitioners have gone as far as to say that all costs of new construction commissioning *should* be recovered through cost savings in project delivery (with energy savings being icing on the cake). Dorgan, et al.[13] cite seven examples in which these non-energy benefits amount to 1.7 to 22 times the cost of commissioning, with a combined value of over $2.2 million in savings before energy savings are counted.

They cite four examples in high-tech buildings in which new construction commissioning saved $319,000, $400,000, $425,000, and $500,000 in project delivery costs, for a science center, hospital, vivarium, and science building, respectively (before energy savings were counted). These benefits resulted from:

- Eliminating change orders;
- Eliminating requests for information;
- Proper system/component selection; and
- Reducing contractor callbacks and accelerated date of proper operation.

Commissioning Continuity

We identified a rare opportunity to follow a high-tech building through its initial commissioning process (design, construction and start-up) and its subsequent commissioning as an existing building. The data tells an important story of the importance of embedding commissioning throughout a building's life cycle (sidebar case study, Page 22). The building was at Lawrence Berkeley National Laboratory's Molecular Foundry facility. The complex, high-tech building contained laboratory spaces, as well as data processing and cleanroom environments.

Considerable energy savings were garnered during the new construction phase, with a payback time of 0.4 years. A comparable level of savings was subsequently obtained when new commissioning opportunities arose after occupancy, with a shorter payback time of 0.2 years.

Conclusions

In keeping with the energy intensities characteristic of high-tech facilities, the value of commissioning new buildings and retro-commissioning them periodically during their service lives is considerable.

Payback times well under a year can be routinely achieved, and in many cases first cost savings create instant positive cashflow. Benefits manifest in energy savings and in non-energy benefits including enhanced safety and productivity. In our analysis of a range of building types, the high-tech buildings cohort was particularly cost-effective, and saved substantially higher amounts of energy due to their energy intensiveness.

Tapping the potential requires continued demonstration of cost-effectiveness, customer and practitioner training to ensure persistence, as well as greater recognition of the opportunities and improved support from the energy policy community.

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