Laboratories for the 21st Century: Case Studies

Doug Lockhart /PIX14838

Laboratory Type
- ☑ Wet lab
- ☑ Dry lab
- ☑ Clean room

Construction Type
- ☑ New
- ☐ Retrofit

Type of Operation
- ☑ Research/development
- ☐ Manufacturing
- ☐ Teaching
- ☑ Chemistry
- ☑ Biology
- ☑ Electronics

Service Option
- ☑ Suspended ceiling
- ☐ Utility service corridor
- ☐ Interstitial space

Featured Technologies
- ☑ Fume hoods
- ☑ Controls
- ☑ Mechanical systems
- ☑ Electrical loads
- ☑ Water conservation
- ☐ Renewables
- ☑ Sustainable design/ planning
- ☐ On-site generation
- ☑ Daylighting
- ☑ Building commissioning

Other Topics
- ☐ Diversity factor
- ☐ Carbon trading
- ☐ Selling concepts to stakeholders
- ☑ Design process

LEED Rating
- ☐ Platinum
- ☑ Gold
- ☐ Silver
- ☐ Certified

The Molecular Foundry is a new, state-of-the art user facility for nanoscale materials on the research campus of Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California. Like the foundries of the industrial revolution, the facility will be involved in building novel, possibly even revolutionary structures; however, here the structures will be built atom-by-atom on a nanoscale. These novel devices could include very precise nanosensors for detecting environmental contaminants, highly efficient and inexpensive flexible solar cells, and ultrafast nanocomputers.

The facility was completed in April 2006 as one of five U.S. Department of Energy Office of Science Nanoscale Science Research Centers scheduled for construction over the next few years. The aim is to establish a hub for collaborations among researchers from such diverse disciplines

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as materials science, biology, electrical engineering, physics, and chemistry. As a Laboratories for the 21st Century (Labs21) Pilot Partner, LBNL set several important sustainable design goals for design and construction:

- Obtain institutional buy-in at high levels and engage all relevant departments, from the Directorate to Health and Safety
- Achieve a U.S. Green Buildings Council (USGBC) Leadership in Energy and Environmental Design (LEED™) Gold rating and conduct pilot testing of the *Labs21 Environmental Performance Criteria* (EPC)
- Incorporate features that minimize energy use, including an energy-efficient chiller and boiler plant with controls that permit temperature and pressure adjustments in heating, ventilating, and air-conditioning (HVAC) equipment and water systems
- "Right-size" the generators, transformers, and HVAC system based on submetered data from several existing laboratories
- Apply efficiency strategies to the design of the specialized, energy-intensive spaces (labs, a cleanroom, and a server room) and have the capacity to further test enhanced approaches to energy savings
- Include a robust building commissioning activity and extensive monitoring
- Minimize the energy use associated with transportation for collaborating researchers located elsewhere on the site
- Employ green-building strategies beyond those for energy systems, such as low-emissions construction materials, construction waste management, and indoor/outdoor water use efficiency.

This project resulted in estimated annual energy-use savings of approximately 8,500 million Btu and annual energy cost savings of about $55,000. The value of the Labs21 contribution to the project over a 3-year period was $36,000. Given that the Labs21 program had a significant influence on the outcome of this project, we estimate that at least 30% of the expected annual savings can be attributed to Labs21 support. This represents a 2.2-year simple payback.

This case study is one in a series produced by Labs21, a joint program of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE). Geared toward architects and engineers familiar with laboratory buildings, this program encourages the design, construction, and operation of safe, sustainable, high-performance laboratories.

Project Description

The Molecular Foundry facility encompasses 95,692 gross ft^2 and includes a six-story, 89,224-ft^2 laboratory building and a 6,468-ft^2, two-story utility plant containing boilers, chillers, an electrical substation, and an emergency generator room. The facility supports users in the areas of nanolithography; organic, inorganic, and biological nanostructures; and the theory, simulation, imaging, and manipulation of nanostructures. Technology outreach is a key area of emphasis. The facility can accommodate approximately 40 visitors or users at one time.

The total construction cost of the project was $52 million ($543/gross ft^2). The total project cost including research equipment is $85 million. The design team included the San Francisco office of the SmithGroup (architect), HYT (fire protection), EWA (laboratory planners), and Gayner Engineers (mechanical and electrical engineers). CH2MHill was the commissioning agent. The construction was managed by Rudolph and Sletten, Inc., of Foster City, California.

The facility is situated on a very steep slope in the Berkeley hills between two adjacent buildings. It requires about 70 ft of earth retention on the east side. The site drops 70 ft vertically per 200 linear ft, for a 35% grade. Burying the building's first two floors helped to shield sensitive nanotechnology equipment from vibrations.

The main entrance is thus on the third floor, which houses offices and common spaces. The entire level 1 is built on grade and provides a low-vibration, low-electromagnetic-field and acoustically shielded laboratory with state-of-the-art imaging and manipulation tools. On the second floor is a cleanroom containing areas of different cleanliness. In a cleanroom, the air is highly filtered to keep out impurities. The total cleanroom area is approximately 4,600 ft^2 with about 1,100 ft^2 at ISO Class 5 (FS Class 100). A mini-environment room with tight temperature control houses the nanowriter, the most specialized and sensitive equipment in the cleanroom.

An ISO class 5 cleanroom, formerly defined as FS Class 100, is one in which the number of particles that are 0.5 micron in diameter or larger does not exceed 100/ft^3.

Staff enter the cleanroom suite through a gowning area. A windowed area on one side allows visitors to observe the suite's interior. The two exterior windows are double-paned with a film that blocks ultraviolet rays (a unique feature for a cleanroom) but allows daylighting and views. Figure 1 shows the second-floor plan.

The Molecular Foundry was constructed to California Building Code H-8 occupancy requirements (based on the Uniform Building Code). It was designed

for approximately 140 occupants, including up to 36 students and postdoctoral fellows. The utility plant is a separate structure located in the hillside north of the Foundry under a landscaped terrace to minimize its visibility to those entering the facility.

Layout and Design

The building program includes three main functional components: labs, offices, and space for interaction and collaboration. Labs and offices are linked to facilitate interactions, accommodate visitors, and create a working environment that stimulates the intellectual advancement of the nanosciences.

Lab areas for "making science" (physical development) are on the east end of each rectangular floor plate; offices on the west end of each floor plate are for "thinking science" (conceptual development). Interaction and collaboration spaces are between labs and offices to help connect people and foster information exchange. The long sides of the rectangular floor plate face north and south, which is optimal for daylighting. Figure 2 on page 4 shows the exterior view. The building's primary mass emerges from the hillside between two adjacent buildings to create an integrated composition of structures.

Laboratory space makes use of a common module to provide flexibility and an ordered, modular distribution of utilities and services. The laboratory planning module selected is 12 ft wide and 24 ft deep. Most labs are 24 ft by 24 ft (equivalent to 2 modules). All labs are based on this planning module. A typical fume hood is 8 ft long and 3 ft 6 in. deep. Table 1 on page 4 shows a space breakdown of the Molecular Foundry building.

Utility Servicing

Because of Building Code H8 requirements, each floor is divided into two fire safety areas by a two-hour-rated walls. Two vertical shafts per area provide space for routing exhaust and supply ductwork. Each area is served by a dedicated air handler and two dedicated exhaust fans. The utility building is next to the Molecular Foundry, so pipes run between the two buildings.

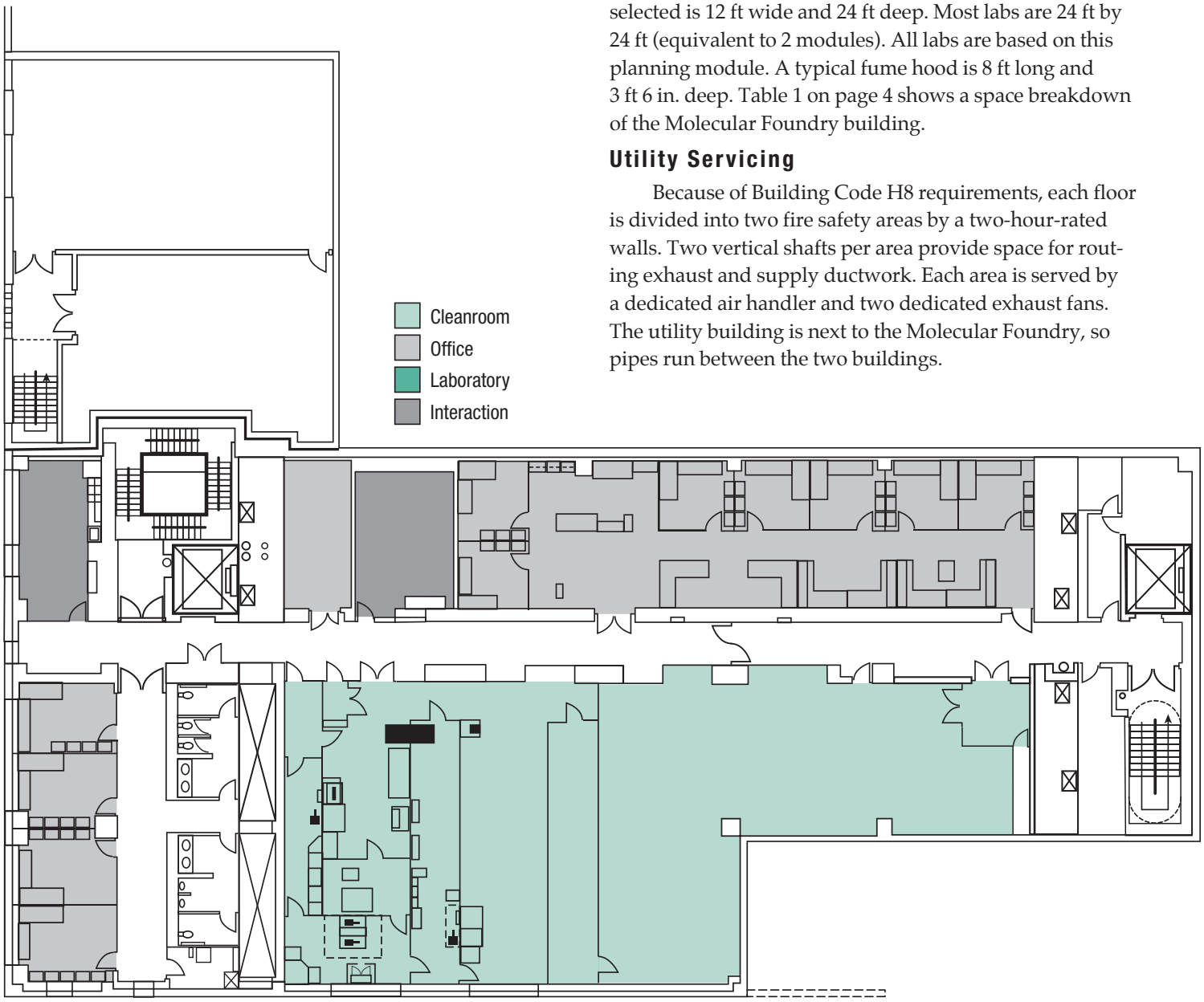

Figure 1. Floor plan for the second floor

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Figure 2. Exterior view (south side) of the Molecular Foundry

Table 1. Molecular Foundry Space Breakdown

(Net ft^2, unless otherwise noted)

Function	Size (ft^2)	Percentage (1)
Laboratory space	26,580	52%
Offices and office support areas	21,256	42%
Misc. assigned space	3,149	6%
Total net ft^2	50,985	100%
Other (2)	44,707	
Total gross ft^2	95,692	

Notes:

1. The percentage shows a breakdown of net ft^2 only. Net ft^2 equals gross ft^2 minus "other."
2. "Other" includes circulation, toilets, stairs, elevator shafts, mechanical and electrical rooms and shafts, and structural elements like columns and walls. The net-to-gross-ft^2 ratio is 53%.
3. Table 2 calculations use 89,224 gross ft^2 in the denominator for the laboratory building only.

Main air handlers and exhaust fans are on the roof. The air handler for the cleanroom is on the level 1 loading dock area.

Design Approach

The teamwork in the design and construction phases went beyond standard practice and contributed significantly to the holistic design. Institutional participation was achieved across many major departments at this 4,000-person DOE National Laboratory campus, from top laboratory management to environmental health and safety personnel.

An energy design charrette was held at the project's inception, a Sustainability Report was created, and regular team meetings focused on green design. In addition, input was sought from the Labs21 program, and all stakeholders were involved in a highly productive value-engineering process that focused on real value.

Technologies Used

Site

The facility was built on a largely undisturbed site adjacent to open space. Including six stories minimized the building's footprint, and more than 50% of the site is landscaped with native plants. There is good access to public transportation, and LBNL's biodiesel-powered shuttle system minimizes car travel around the 200-building campus. Bike racks are also available.

As recommended in EPC, an independent consultant conducted wind tunnel modeling of the Molecular Foundry and adjacent buildings to determine air effluent and intake locations. The design team then incorporated the mitigation measures required and implemented various strategies that would qualify for the EPC safety and risk management water effluent credit, including sink drain plugs, raised lips at cup sinks, and acid and solvent waste collection in the cleanroom.

Energy Efficiency

Right-sizing. LBNL measured electrical loads in three other campus laboratories by submetering the lab spaces to obtain a more accurate characterization of end-use loads so that electrical and mechanical equipment could be sized intelligently. Mechanical and electrical systems in the labs were originally designed for 25 W/ft^2. This was reduced to 15 W/ft^2 after monitoring results were evaluated.

The size of the electrical system (which includes transformers, switchgear, panel boards, cable, and conduit) was reduced by 38%, and the HVAC system by about one-third, saving $2.5 million in first costs. Air handlers

were reduced from a total of 180,000 cubic feet per minute (cfm) to 120,000 cfm; boilers were downsized from a total of 10 million British thermal units per hour (Btu/hr) to 6.8 million Btu/hr; chillers were reduced from a total of 800 tons to 525 tons; and cooling towers downsized from a total of 2,200 gallons per minute (gpm) to 1,500 gpm. Electrical 12-kV to 480-V substations were downsized from 4,000 kVA to 2,500 kVA, and the emergency generator from 500 kVA to 438 kVA.

The planning team also discussed critical loads needing backup generation. As a result, the emergency generator was reduced 12%, from 500 kVA to 438 kVA. Planned fuel storage was reduced from 96 hours to LBNL's standard 24 hours, which reduced the size of the utilities building as well. The resulting savings are not part of the $2.5 million first-cost savings.

The building's energy performance was modeled to be 25% below the California Title 24 standard and 28% below Title 24 when including only LEED-regulated loads. According to USGBC guidelines, this is equivalent to 35% less energy than buildings use that are compliant with American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1 (1999). The simulation assumed a process load of 6.1 W/ft^2 in the labs and 2.2 W/ft^2 in offices.

The building's energy efficiency measures include these:

- Variable-air-volume (VAV) systems for offices and labs (1 cfm/ft^2 lab minimum air flow)
- Premium efficiency chiller plant (chillers at 0.37 kW/ton), and premium efficiency motors and variable-frequency drives throughout the HVAC system (pumps, chillers, towers, and fans)
- Heating coils designed for an entering water temperature of 135°F and a typical leaving temperature of 100°F, to take full advantage of four 1.7 million Btu/hr high-efficiency (94%) modulating and condensing boilers that are half the size of a fire-tube boiler
- Lower air handler filter and coil air flow face velocities than conventional ones (approximately 425 feet per minute [fpm] vs. 500 fpm)
- Electronic (Strion) filters rather than conventional bag filters for lower pressure drop
- Double-pane windows; low-e and spectrally selective window coatings
- T-5 bulbs in lighting systems with bilevel switching and occupancy-based controls
- Energy-efficient elevator system with no machine room
- Energy-related practices such as nighttime setbacks of non-lab temperatures, VAV hoods, ongoing utility trend analysis, scheduled filter replacements and low-maintenance electromagnetic water treatment for cooling towers
- Compressed air generated and distributed to labs at two air pressures to save energy.

Cleanroom. The cleanroom contains premium-efficiency fan-filter units (FFUs) with advanced speed controls to support demand-controlled VAV. The units consist of a small fan, a controller, and an enclosed HEPA/ULPA filter. They maintain specific airflow, typically measure 2 ft by 4 ft (as at the Foundry) or 4 ft by 4 ft, and are usually installed in ceiling grids. LBNL's test for evaluating FFU performance yields baseline information on energy use and air movement performance. LBNL's research found that FFU performance varies by a factor of three for commercially available units. To insure optimum performance, premium-efficiency FFUs were specified for the Foundry.

The cleanroom fan system was designed so that each FFU can be individually controlled. The system is also in place to monitor the particles in the space in order to better control air flow in the cleanroom (see the sidebar titled "Cleanrooms and Data Centers").

Server room. This room employs a hot/cold aisle configuration and the building's high-efficiency central air-handling unit, including an outside-air economizer. In this configuration, the front sides of computer servers on racks face one another across a "cold aisle," where supply air enters the room. The back sides of the server racks face the "hot aisle," where the return air ducts are.

Water Efficiency

The building is designed to operate without using once-through process cooling water, per the Labs21 EPC. Instead, a closed-loop recirculating process cooling water system is provided to all labs. Process cooling water is cooled via a heat exchanger by cooling towers. The building uses 0.5 gpm flow restrictors on lavatory faucets for water and energy savings, as well as waterless urinals.

An electromagnetic water treatment system on the cooling towers reduces total water consumption and the amount of chemicals released to the atmosphere and the sewer. Electronics rather than chemicals are used to reduce scale build-up in the cooling tower plumbing system from calcium or magnesium carbonate in the water. The landscaping employs drought-tolerant plantings and a water-efficient irrigation system.

Indoor Environmental Quality

Indoor air quality (IAQ) elements include carbon dioxide monitoring and control of outside air for ventilation. A construction IAQ management plan was developed to maintain cleanliness in the air-handling system during construction and before occupancy. The design team ensured that all adhesives and sealants, paints and coatings, carpet, and composite wood meets or exceeds LEED requirements for volatile organic compounds.

Materials

To identify products durable enough for a laboratory environment, in the design phase LBNL researchers worked with SmithGroup to test finishes and materials used in lab areas. SmithGroup provided samples of flooring and laboratory countertop materials so researchers could test the chemicals they use over those surfaces. A phenolic resin top was selected for lab countertops that performed better than epoxy tops. Several types of vinyl flooring and a linoleum material were tested for flooring. The linoleum did not perform well, so vinyl flooring was selected.

Recycled content was specified whenever possible, and about 85% of all building construction waste was recycled. Almost all wood is sustainably harvested as certified by the Forest Stewardship Council. Low-emission carpeting, paint, sealants and adhesives, along with rapidly growing renewable materials such as bamboo flooring in the lobby and interaction spaces, create a healthy indoor environment. LBNL is also developing an information system to manage hazardous material handling.

Cleanrooms and Data Centers

As defined by ISO 14644-1, a cleanroom is "a room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the room and in which other relevant parameters, e.g., temperature, humidity, and pressure, are controlled as necessary." The ISO standard defines cleanrooms by particle size per cubic foot.

Cleanrooms and data centers can be 100 times as energy-intensive as conventional office buildings. They can require filtered, conditioned, and recirculated air at rates up to 600 air changes per hour. Thus, they merit special attention when it comes to energy management.

Energy demand for data centers is growing steadily, and electric utilities receive numerous requests for power for new facilities. Understanding this market is challenging, and there are many opportunities for energy efficiency improvements. See LBNL's Web site, High-Performance Buildings for High-Tech Industries, for more information about research in technology development, benchmarking, and best practice strategies to reduce energy use in cleanrooms and data centers: http://hightech.lbl.gov.

Commissioning

Independent third-party commissioning of this building was extensive. Building commissioning is a systematic, documented process of ensuring that operational needs are met, that building systems perform efficiently, and that building operators are properly trained. An investment in commissioning at the project's start, approximately 0.5% of the construction cost, can lower annual operating costs.

Commissioning includes testing to select the minimum static pressure for building operation. This involves stressing the system by raising all fume hoods and sashes to the stops at 18 in., turning the cooling to full, then checking to see if hoods are operating at the required face velocity. The design drawings call for using this procedure to determine the required static pressure for both supply and exhaust systems, starting at 1.5 in. water column.

The ANSI Z9.5 Laboratory Ventilation Standard is being met by fume hood monitoring and alarms, automated lab pressure controls, and volumetric metering of supply air. Each fume hood was tested for containment in accordance with ASHRAE 110-1195 (1995).

Building Metrics

Building metrics calculations, based on design data, are shown in Table 2. In this building, the ratio between brake horsepower and motor horsepower was unusually high because motors were sized for future growth. Brake horsepower was used in ventilation calculations.

Measurement and Evaluation Approach

A Web-based energy monitoring and control system allows extensive energy and water metering via thousands of monitoring and control points, three gas meters, and nine water meters. As stipulated in its prime contract with DOE, LBNL will spend 2% of the facility replacement plant value, about $830,000 per year, on operations and maintenance. Permanent metering is provided for lab power loads; temporary clamp-on metering can be used on the lab panel level.

Table 2. Building Metrics for the Molecular Foundry

System	Key Design Parameters	Annual Energy Usage (based on design data)
Ventilation (sum of wattage of all the supply and the exhaust fans)	Supply= 0.71 W/cfm Exhaust = 0.40 W/cfm Total = 1.1 W/cfm (1) (1.1 cfm/gross ft^2; 2.0 cfm/net ft^2 and 3.8 cfm/gross ft^2 of labs)(2)	16.2 kWh/gross ft^2 (3)
Cooling plant	525 tons, 0.37 kW/ton	6.3 kWh/gross ft^2 (4)
Lighting	1.18 W/gross ft^2 weighted average	5.3 kWh/gross ft^2 (5)
Process/plug	2.5 W/ft^2 weighted average	10.3 kWh/gross ft^2 (6)
Heating plant	4 @ 1.7 million Btu/hr, 94% efficiency	69,000 therms (77 kBtu/ft^2/yr) (7)
Total		38.2 kWh/gross ft^2/yr (estimate based on design data for electricity only) 130.4 kBtu/gross ft^2/yr for electricity only (8) 207 kBtu/gross ft^2/yr for electricity and gas $2.68/gross ft^2/yr estimated annual cost for electricity and gas.

Notes:

1. 147 hp (supply) x 746 W/hp/(155,000 cfm (supply) + plus 75 hp (exhaust) x 746 hp/139,000 cfm (exhaust) = 1.1 W/cfm. (Note that in this case study brake rather than motor hp was used in the calculations).
2. 100,000 (total cfm based on exhaust)/89,224 gross ft^2 = 1.12 cfm/net ft^2; cfm/50,985 net ft^2 = 1.96; cfm/26,580 net ft^2 of labs = 3.76. (Note: Two of the building's exhaust fans, totaling 39,000 cfm, are return fans, so they were subtracted in calculating exhaust cfm; therefore, the exhaust total used is 100,000 cfm.)
3. 0.40 W/cfm x 139,000 cfm/gross ft^2 (exhaust) + 155,000 cfm/gross ft^2 x 0.71 W/cfm (supply)/89,224 ft^2 x 8760 hours/1000 = 16.2 kWh/gross ft^2 (30.5 kWh/net ft^2).
4. 0.37 kW/ton x 525 tons x 2,890 hours/89,692 gross ft^2 = 6.31 kWh/gross ft^2 (assumes cooling runs 33% of the hours in a year).
5. 1.18 W/gross ft^2 (weighted average) x 1820 hours/1000 = 5.33 kWh/gross ft^2 (assumes that lights are on 87.2 hours/week).
6. 2.46 W/gross ft^2 (weighted average of 6.1 w/ft^2 in lab areas and 2.2 w/ft^2 in non-lab spaces) x 0.80 x 5256 hours/1000 = 10.34 kWh/gross ft^2 (assumes that 80% of all equipment is operating 60% of the hours in a year).
7. The annual energy usage for heating is based on design load and climate data.
8. Estimated data are presented in site Btu (1 kWh = 3412 Btu). To convert to source Btu, multiply site Btu for electricity by 3. [Note: Berkeley, CA, has approximately 1676 heating degree-days and 81 cooling degree-days (based on San Francisco, CA, weather data).]

Note: Gross ft^2 calculations excluded the utility building

Summary

The Molecular Foundry incorporates Labs21 principles in its design and construction. The design includes many of the strategies researched at LBNL for energy efficent cleanroom and data centers. The result is an energy efficient high-performing sustainable laboratory.

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See also www.labs21century.gov/toolkit/bp_guide.htm for these best practice guides:

Minimizing Reheat Energy Use in Laboratories

Modeling Exhaust Dispersion for Specifying Exhaust/ Intake Designs

Right-sizing Laboratory Equipment Loads

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