LBNL-50599

HIGH-PERFORMANCE LABORATORIES and CLEANROOMS

A TECHNOLOGY ROADMAP

Developed by:

Lawrence Berkeley National Laboratory with input from industry partners representing high tech facility design and operation, industry associations, research laboratories, energy consultants, and suppliers to the high tech industry.

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Sponsored by:

The California Energy Commission
Public Interest Energy Research (PIER)

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High-Performance
Laboratories and Cleanrooms

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Executive Summary

The California Energy Commission sponsored this roadmap to guide energy efficiency research and deployment for high performance cleanrooms and laboratories. Industries and institutions utilizing these building types (termed high-tech buildings) have played an important part in the vitality of the California economy. This roadmap's key objective is to present a multi-year agenda to prioritize and coordinate research efforts. It also addresses delivery mechanisms to get the research products into the market.

Because of the importance to the California economy, it is appropriate and important for California to take the lead in assessing the energy efficiency research needs, opportunities, and priorities for this market. In addition to the importance to California's economy, energy demand for this market segment is large and growing (estimated at 9400 GWH for 1996, Mills et al. 1996). With their 24hr. continuous operation, high tech facilities are a major contributor to the peak electrical demand.

Laboratories and cleanrooms constitute the high tech building market, and although each building type has its unique features, they are similar in that they are extremely energy intensive, involve special environmental considerations, have very high ventilation requirements, and are subject to regulations—primarily safety driven—that tend to have adverse energy implications. High-tech buildings have largely been overlooked in past energy efficiency research.

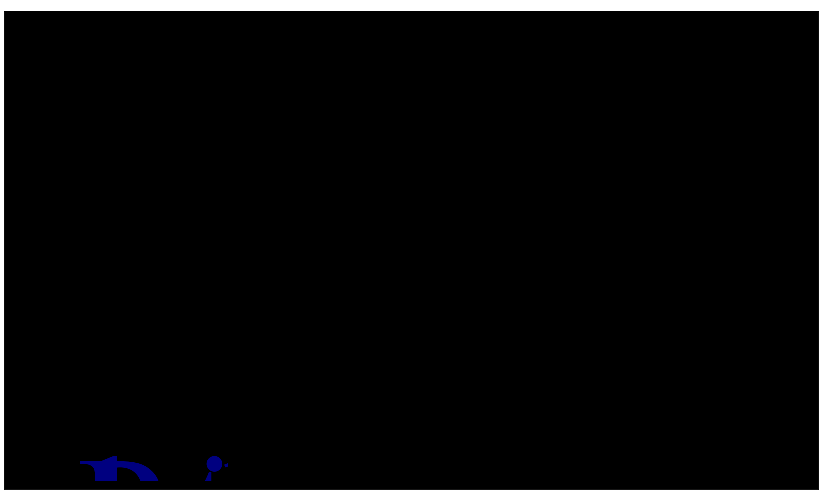


Figure 1. California cleanroom square footages (Mills et al. 1996).

Many industries and institutions utilize laboratories and cleanrooms. As illustrated in **Figure 1**, there are many industries operating cleanrooms in California. These include semiconductor manufacturing, semiconductor suppliers, pharmaceutical, biotechnology, disk drive manufacturing, flat panel displays, automotive, aerospace, food, hospitals, medical devices, universities, and federal research facilities.

The laboratory and cleanroom buildings for these industries and for many institutions, serve an integral function with the processes they contain. The buildings' HVAC systems often drive the energy consumption of these industries (estimated at 50% or more of the total energy use). Although activity requiring a laboratory or cleanroom varies greatly, the high tech building systems are similar and have common opportunities for improvement. The roadmap is thus crosscutting and involves many industries and institutions.

Vision

By the year 2012:

Achieve a 50% reduction in new facilities (30% for retrofit) energy intensity for comparable production, while maintaining or improving productivity and safety.

Energy performance benchmarking is available for a wide population of facilities.

Measurement systems are in place for continuous monitoring and improvement.

Many challenges facing this market have been identified through prior research and through industry input:

Key Challenges:

Collaboration with industry associations, codes and standards bodies, public goods sponsors and associations, universities, and other researchers.

Laboratories and Cleanrooms complexity and diversity make measurement and comparison a challenge.

Research and Development

- To refine and develop scientific bases for industry "rules of thumb".
- To develop new technologies and strategies.
- To improve tools for design, operation, and commissioning.

The participants in the roadmap effort identified the following issues as most important for the research and market transformation agenda:

1. Understanding the market
2. Benchmarking and identification of best practices
3. Planning and design tools
4. Heating, Ventilating, and Air-conditioning (HVAC)
5. Exhaust Systems and Devices
6. Controls and Monitoring
7. Information Technology for enhanced performance
8. Mini-environments
9. Lighting
10. Process systems
11. Codes and Standards
12. Collaboration
13. Market transformation and technology transfer

It is hoped that this roadmap will better align the efforts of facility owners, operators, and designers; researchers; electric utilities; and industry professional organizations. This will minimize duplication of effort and allow simultaneous advancements in many areas. New technologies and programs will be identified and developed by working with industry partners.

Introduction

What does high-tech mean for California? According to the American Electronics Association (www.aeanet.org), California statistics are:

California leads the nation in 12 of 13 high-tech industry segments

More than 31,923 high-tech establishments in 1999, ranked 1st nationwide 973,555 high-tech workers (the most in the nation)

333,400 jobs added between 1994 and 2000, the largest increase of all states

High-tech firms employ 77 of every 1,000 private sector workers, ranked 4th nationwide

1st in semiconductor manufacturing employment with 71,600 jobs

A high-tech payroll of $73 billion in 1999, ranked 1st nationwide

High-tech workers earned an average wage of $83,103 (2nd ranked), or 123% more than the average private sector wage

High-tech exports totaled $67.5 billion, ranked 1st nationwide

High-tech exports represented 56% of California’s exports

Venture capital investments of $42 billion, ranked 1st nationwide

R&D expenditures of $44 billion in 1998, ranked 1st nationwide

These figures only consider electronics businesses; the importance jumps substantially when considering the other industries and institutions that utilize high-tech laboratories and cleanrooms. For example, according to the California State Legislature's Select Committee on Biotechnology, the Bay Area is home to over 645 biomedical companies employing over 80,200 workers, and is the nation's leader in biotechnology. Ernst and Young reports that the Biotech industry could grow at 30 to 40% in the upcoming year. High-tech buildings support these industries and they are critical to the California economy. They are also energy intensive, so energy efficiency gains are beneficial to the larger California economy and also provide significant reduction in total electrical demand.

Buildings for high-tech industries and institutions typically have demands for high reliability and safety to both protect the workforce and to ensure satisfactory performance of the process occurring therein. Once these buildings are operating satisfactorily in terms of production and safety, there is little incentive to "upset the applecart" to look for efficiency opportunities. As a result, improving energy efficiency has been a low priority. The economic downturn of 2001 and energy disruptions beginning in 2000 provided stimulus to many operators of these facilities to look for opportunities to save energy. With 24/7 operation in most cases, high-tech facilities are major contributors to peak electrical demand.

Many firms realized that lowering their energy demand has considerable economic rewards. In some locations, such as Silicon Valley, industries realized that collectively lowering electrical demand not only improved, their own competitiveness but also improved overall electrical grid reliability. Yet most facility managers and designers are not aware of specific technologies and strategies that can be implemented. Benchmarking, charrettes, and case studies have shown that carefully considered strategies and new technologies could maintain or improve existing levels of production and worker safety while achieving large energy savings. (Sartor, et al. 2001. Sartor, et al. 1999)

The technologies and strategies outlined in this roadmap involve a portfolio spanning better implementation of well-understood strategies (such as improvements to chilled water system efficiency) to research needs for as yet undiscovered technologies. New inventions are needed to break current paradigms and to take efficiency to the next level-such as developing a high-performance fume hood to reduce airflow in laboratories; or developing new, more efficient filter media for use in cleanrooms.

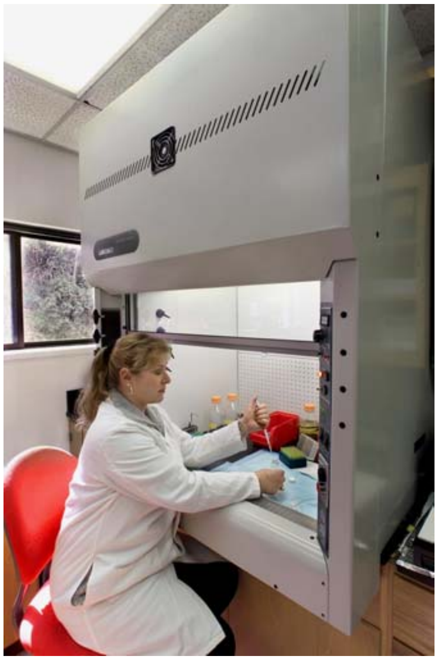


Figure 2. Berkeley fume hood.

Experience has shown that market acceptance of new products and strategies works best when multiple benefits are (or could be) provided (Mills et al. 1994; Sartor et al. 2001). In high-tech Buildings, there are numerous areas where non-energy benefits may be the ultimate driving force and need to be exploited to achieve energy reduction goals. For example, the high-performance fume hood, **Figure 2**, under development by LBNL improves containment of hazardous materials while achieving a 50–70% reduction in airflow. And in cleanrooms, reduction in recirculated air velocity may actually improve production yields. Likewise, new inventions, such as a particle counter that, if developed, could survey an entire cleanroom to pinpoint areas of leakage or contamination, detect hazardous gases, and could be used to control (reduce) airflow. Therefore as the roadmap seeks to improve the efficiency of high-tech industries, it will also improve the overall performance and productivity of buildings serving those industries. Additional benefits in improving maintenance, operations, and safety will be important drivers in advancing the efficiency agenda.

There are many energy efficiency research needs that can be categorized as follows:

1. **Validate or refine industry "rule of thumb" criteria, which may not have a sound scientific basis. Develop scientifically based criteria where none exists.** For example, scientific justification is needed to establish appropriate ventilation requirements in laboratories and cleanrooms to satisfy safety and efficiency concerns.

2. **Develop new products, technologies, and strategies that currently do not exist.** Many elements of cleanroom and laboratory systems hold great potential for improvement. Among the possibilities are new, more efficient filtration, efficient air recirculation, novel control schemes based upon cleanliness monitoring using whole area particle counters, better use of enclosure technology, etc. Areas identified to date are included in the roadmap and on-going dialogue with industry and inventors will likely identify additional opportunities.

3. **Improve tools for design, operation, and commissioning of high tech facilities.** These tools are a natural extension of currently available tools and practices developed for commercial buildings or other system components. Programming guides (http://ateam.lbl.gov/cleanroom/guide/ProgrammingGuide-LBNL49223.pdf) and Design Guides (http://ateam.lbl.gov/Design-Guide/index.html), Design Intent Tools, Self-benchmarking Tools, Simulation Tools, improved Airflow Modeling, rating sustainability as with the LEED rating system (www.usgbc.org/programs/leed.htm), and others will provide needed guidance.

4. **Evaluation of energy performance of specialized products used in high tech buildings similar to DOE/EPA's ENERGY STAR work in appliance standards.** Lack of standardized testing and reporting of performance currently leads owners and designers to make selections with minimal consideration of energy performance. Examples of this need are fan-filter units (**Figure 3**), commonly used in cleanrooms and fume hoods in laboratories. There currently is no standard testing and reporting of operating performance making it impossible for owners and designers to make informed decisions related to energy performance as well as other key operating parameters.

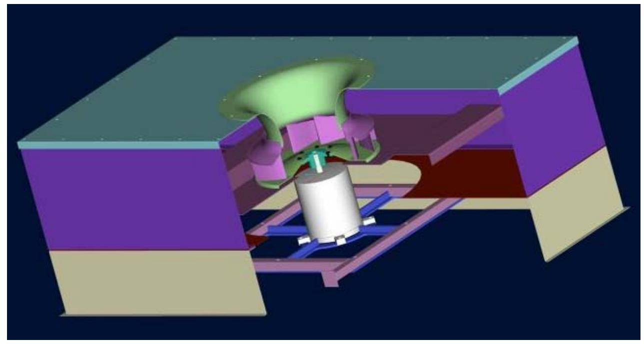


Figure 3. Fan-filter unit schematic.

This roadmap identifies R&D opportunities that address each of these areas.

Vision and Drivers

The vision put forth by industry representatives involves the following ten-year goals:

Achieve 50% reduction in building energy use for comparable production in new construction while maintaining or improving productivity, and safety.

Benchmark energy use in a wide population of facilities. Use measurement systems for continuous monitoring and improvement.

Improve use of sustainable technologies.

This roadmap's key objective is to present a multi-year agenda to prioritize and coordinate research efforts. It also addresses delivery mechanisms to get the research products into the market.

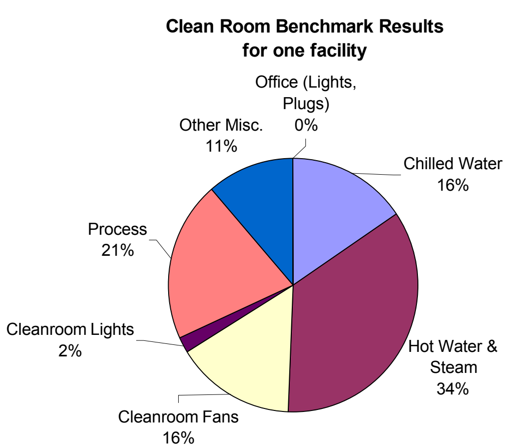
Since laboratories and cleanrooms are common in many industries and institutions, there are many diverse stakeholders. Organizations include semiconductor manufacturing, semiconductor suppliers, pharmaceutical, biotechnology, disk drive manufacturing, flat panel displays, automotive, aerospace, food, hospitals, medical devices, universities, and federal research facilities. Industry associations such as Sematech, IDEMA, ASHRAE, and the Silicon Valley Manufacturers Group, as well as public interest organizations such as the Northwest Energy Efficiency Alliance, and public utilities, are interested in advancing energy efficiency research, but traditionally have not been able to direct resources to this type of research. Much of the market is under-served and has limited resources to apply to energy efficiency since research resources are typically allocated to product development. Much of the federal research and development is directed towards older, more energy intensive industry segments rather than high-tech.

Energy intensity in buildings containing laboratories and cleanrooms is larger than in other building types by factors of 4 to 100. A prior study calculated that high-tech facilities used approximately 9400 GWH of electricity in California in 1996. (Mills et al. 1996) Energy use has continued to increase in these types of facilities due to growth in terms of square footages, wider applications, and through more energy intensive processes. Case studies and industry experience demonstrate that a 50% (or more) reduction in energy usage is possible in these buildings. Since many high tech industries are continually changing their processes and products—resulting in changes to building systems—there are frequent opportunities to make improvements.

Research, if advanced in a number of critical areas, could result in new technologies and practices that will enable the vision for this market to be realized. Research is needed to significantly change the paradigms restricting a leap forward. High-tech buildings are the "racecars" of California buildings. Just as new automotive technologies get introduced in racecars and then find their way into the family car, technologies developed for high-tech buildings will have broad applicability in other building types.

High-tech industries frequently guard information concerning their products and the process (es) used to produce them. Since these are considered proprietary, it is more challenging to develop process system efficiency measures through public goods efforts.

Process improvements tend to be industry/product specific and will require separate industry focus similar to the Department of Energy's "Industries of the Future" industry specific focus. For example, technologies needed to improve efficiency in semiconductor processes will be much different than those needed for the food industry. Efforts to improve industry specific process systems' efficiency will require close partnering with process manufacturers. Although energy is often the most significant operating expense, it represents a small fraction of the overall cost of production. This fact relegates process energy efficiency to a lower priority. The life cycle of a process may also be relatively short (e.g., 1–5 years), while the high-tech building systems remain in service for twenty or more years. Even though there are huge opportunities for efficiency gains in process systems, this area will require a long-term, concentrated focus. High-tech building systems are energy intensive and have crosscutting opportunities for efficiency improvements in similar systems. Consequently, it is logical to assign a higher priority



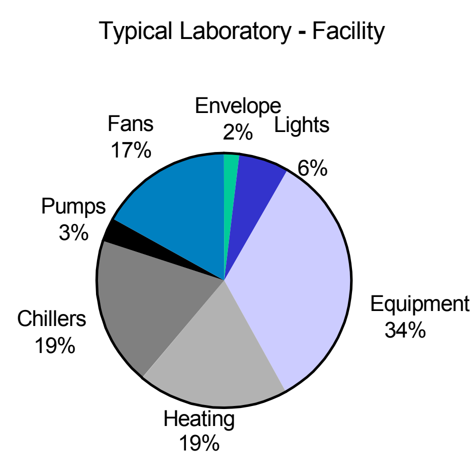


Figure 4. Energy end use.

to energy efficiency research focused on the facility and facility systems. Efficiency improvement in these areas have the broadest applicability and generally will have fewer obstacles to implementation since there is less risk to production. Prior benchmarking and case studies showed that HVAC systems consume the majority of non-process energy in these buildings. For example, **Figure 4** shows the HVAC energy (cleanroom fans, majority of hot water and steam, and majority of chilled water) along with other energy end use in a typical cleanroom facility.

Technology improvements for process systems and equipment will be possible by working with industry partners but there are a number of barriers that must be overcome. There is a general reluctance to implement energy efficiency measures based upon perceived threats to impacts on production, and other more traditional barriers.

Another roadmap objective is to align the efforts of facility owners, operators, and designers; researchers; public goods efforts; and industry professional organizations to the extent possible. By achieving a consensus on the research topics and priorities, and through coordination provided by the California Energy Commission, it will be possible for various research efforts to advance simultaneously. This will minimize duplication of effort and allow advances in many areas simultaneously. New technologies and programs will be identified and developed by working with industry partners.

Longer term, a roadmap should facilitate continuous improvement in energy performance while maintaining or improving health and safety, as well as improving reliability and production for the industries that utilize these types of facilities. Constant improvement due to monitoring against benchmarks, researching and developing more efficient components, implementing innovative system design, and new technologies, will continually improve energy efficiency in these facilities. The roadmap is envisioned to be a living document that will be updated periodically (similar to the SEMI/Sematech roadmaps for achieving excellence in semiconductor manufacturing—listed under factory integration. See SEMI website: http://public.itrs.net/Files/2001ITRS/Home.htm)

The Roadmap Process

The California Institute for Energy Efficiency (CIEE), the Department of Energy (DOE), the Environmental Protection Agency (EPA), and the California Energy Commission's Public Interest Energy Research (PIER) programs have previously sponsored research in a number of areas relating to high-tech buildings. In addition, California utilities, the Northwest Energy Efficiency Alliance (NEEA), the Federal Energy Management Program (FEMP), Montana State University, and others have sponsored various market transformation activities to improve performance in high-tech buildings. LBNL's participation in related ASHRAE and CAL/OSHA committees has also been valuable. In performing this work over the past 7 years, Lawrence Berkeley National Laboratory accumulated a wealth of technical information concerning the current state of high-tech buildings and has continued research in several high impact areas. The following past research has contributed to the understanding of the state of this market and the potential for further significant efficiency gains:

- Literature searches for laboratory and cleanroom facility topics
- Development of Laboratory Design Guide (http://ateam.lbl.gov/Design-Guide/)

- Invention of the "Berkeley Hood"—a high-performance fume hood (http://ateam.lbl.gov/hightech/fumehood/fhood.html)
- Development of computational techniques to optimize the design of air distribution systems
- Design charrettes and case studies for laboratories and cleanrooms (Sartor et al. 1999) (http://ateam.lbl.gov/cleanroom/cases.html)
- Design assistance for federal laboratory and cleanroom facilities
- Energy benchmarking of cleanrooms including development of protocols, metrics, and efficiency opportunities (http://ateam.lbl.gov/cleanroom/benchmarking/index.html)
- Evaluation of energy analysis and design tools used by the industry
- Development of Cleanroom Programming Guide (http://ateam.lbl.gov/cleanroom/guide/ProgrammingGuide-LBNL49223.pdf)
- Development of a Design Intent Tool for laboratory-type facilities. (Sartor et al. 1999)
- Technical support to the EPA/DOE Laboratories for the 21st Century program (www.epa.gov/labs21century/)
- Development of a draft rating system to evaluate the sustainability of laboratory designs (LEED for Labs—based upon commercial building program. (http://www.usgbc.org/programs/index.htm)

Interaction with high-tech industries and institutions has also provided insight into the needs and priorities of the industry. Collaboration with many organizations has helped shape the roadmap topics and their priority. The ASHRAE laboratory and cleanroom technical committees (TC 9.10 and TC 9.11), Sematech, Silicon Valley Manufacturers Group, EPA and DOE's "Labs for the 21st Century", and others continually identify the need to solve new challenges and refine existing practices.

LBNL conducted workshops and participated in others over a three-year period with leading industry firms that have a stake in design and operation of high-tech buildings. These workshops provided considerable insight into the energy research needs for these building types. The affected industries' input directly contributed to the roadmap. Participants included design firms, building operators, researchers, energy service providers, and other stakeholders from a broad cross section of industries. Several workshops were held in locations with high concentrations of high-tech firms in the San Francisco Bay area and in Portland, OR through collaboration with the Northwest Energy Efficiency Alliance. In 2001, three workshops were held and provided the most current information. The technologies, strategies, barriers, and priorities discussed in these workshops are incorporated into the roadmap. The consensus of these workshops forms much of the basis of this roadmap.

Finally, a survey was sent to over 100 individuals involved in high-tech building design, operation, research, or market transformation. The survey requested input on the content and priority of the draft roadmap elements. The responses assisted in assigning priority to agenda items as well as refining the agenda items.

Roadmap

1. Understanding the Market

Issue 1.1: Market assessment and analysis of growth

The high-tech building market in California is dynamic and has experienced rapid growth since its inception. Energy demands for this market were estimated in previous LBNL reports (Mills et al. 1996; Sartor et al. 1999 (http://ateam.lbl.gov/PUBS/doc/LBNL-39061.pdf)). These studies should be further refined and updated to track and predict the impact on California energy resources. In addition, technology changes can dictate rapid changes in energy intensity. For example, changes to processes, which require more stringent cleanliness, can rapidly drive demand to more energy intensive HVAC systems. Conversely, use of new technology such as mini-environments may allow less stringent environments and consequently save energy over current practice. These trends can be qualitatively if not quantitatively tracked.

Possible actions:

- ♦ Perform periodic market assessments to understand and track electrical energy demand for the laboratory and cleanroom market.
- ♦ Analyze growth in this market accounting for growth in terms of square footage and changes due to technology shifts.

Time: On-going periodic reviews

Issue 1.2: Decision-making

In order to transform the high-tech building market, the building owner's key decision makers must see value in making changes. Staff in charge of production as well as those in charge of facility systems must embrace any new strategies or technologies. Frequently, there are perceived risks to production, safety, or reliability, which must be addressed. Research directed at improving efficiency and operating practices in high-tech buildings should include investigation into organizational barriers and develop strategies to overcome them.

Possible actions:

- ♦ Using industry "partners," develop management case studies detailing how key decisions are made and developing recommended approach (es) to implementing energy efficiency changes.
- ♦ Interview various levels of management and operations to understand how decisions are made in budgeting, and adopting new technology or strategies for building systems operation.
- ♦ Perform charrettes involving all stakeholders of high-tech facilities. Record and analyze all barriers introduced by the various participants and develop strategies to overcome them.
- ♦ Develop a behavioral model for decision making for high-tech buildings. Eto, et al. 1996, provides one such model.

Time: Short-term

2. Benchmarking and Best Practices

Determining the current operating efficiency at the building level for this market and finding current best practices is a challenge in the ever-changing environment of high-tech buildings. Cleanroom and laboratory owners and operators know that their facilities are expensive to operate yet they have little information to allow comparison. Consequently, they don't know if the efficiency of their facility is good or bad. Moreover, they do not know how various subsystems or components performance contribute to the overall performance. Benchmarking is identified as a key step to help identify current best practices, set efficiency targets, and identify efficiency opportunities. Once the possibilities using current technology are identified, strategies will be developed to move to broader acceptance of best practices in new construction and retrofit projects.

High-tech buildings are complex and frequently house energy intensive processes. **Figure 5** is a typical semiconductor manufacturing facility. Many variations in processes and systems' designs make it meaningless to compare energy per square foot and create a challenge to find common bases for comparison. Production metrics are usually meaningless when trying to assess the efficiency of a building system or to compare similar systems if different processes and configurations are involved. Useful benchmarking protocols involve metrics that allow comparison of system efficiency across a variety of applications—such as the amount of airflow per unit of energy input (cfm/kW). (Sartor et al. 2001).

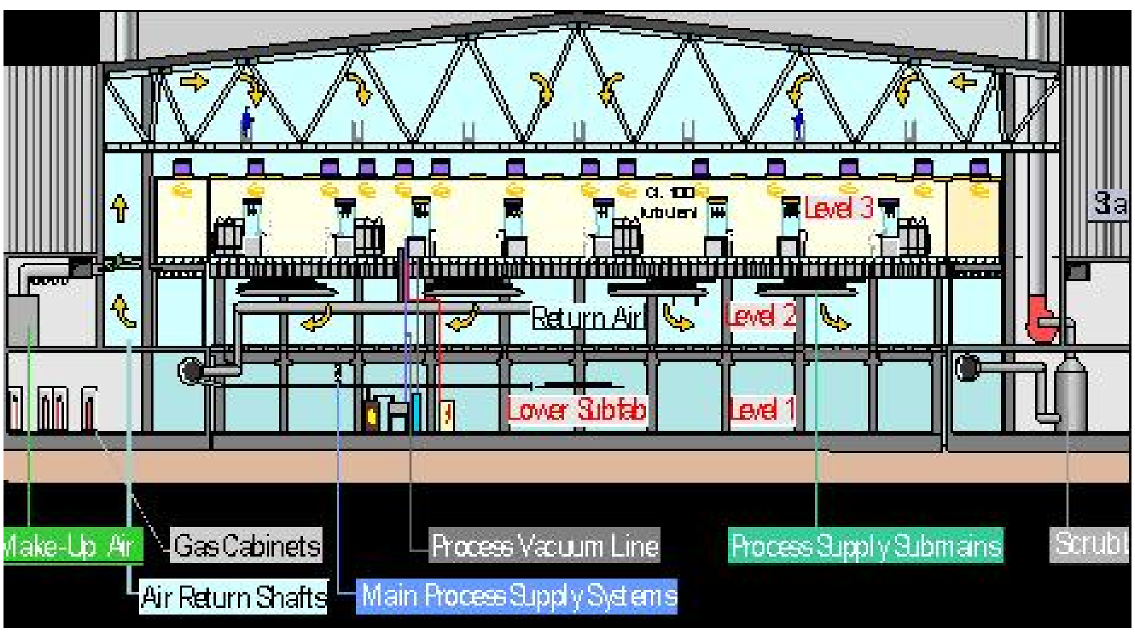


Figure 5. Semiconductor manufacturing facility.

LBNL conceptualized a model based benchmarking schema for use in laboratories through prior PIER research. This concept involved developing a theoretical maximum performance for various operating parameters, which could then be used to compare actual performance to the theoretical maximum. In this way, laboratories performance could be compared (as a ratio of actual to theoretical maximum) even though the configurations could be vastly different. This concept could be further developed for use in laboratories.

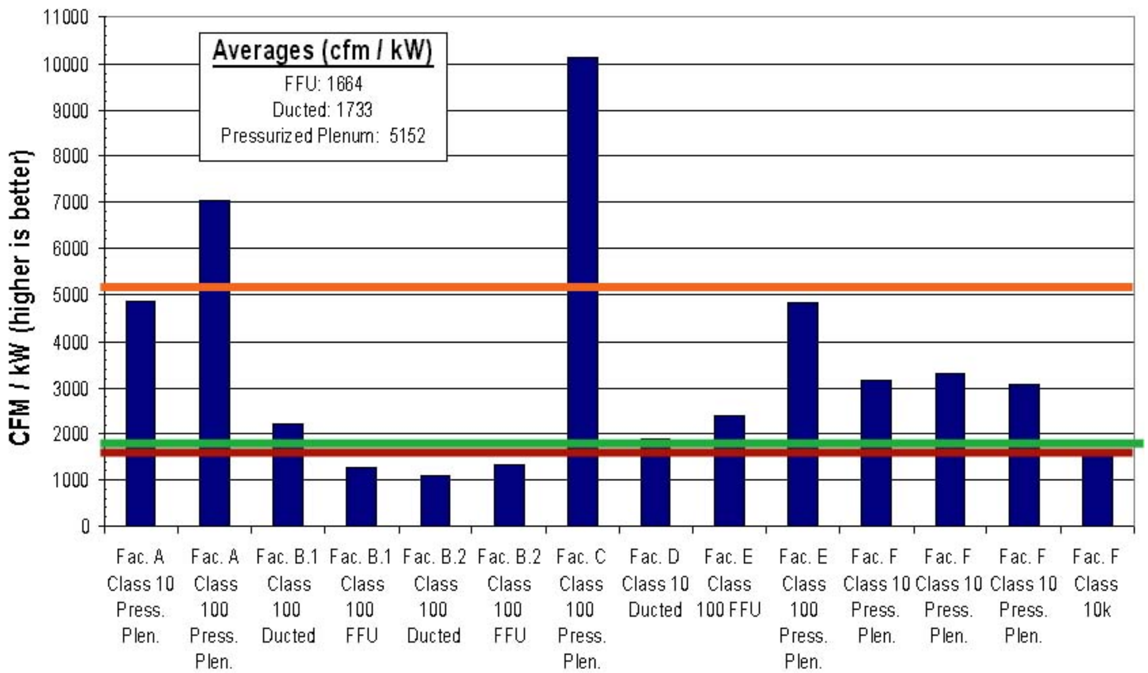


Figure 6. Recirculation air comparison.

LBNL benchmarked a small sampling of cleanroom facilities and observed large variations in performance. **Figure 6** presents a comparison of the cleanroom recirculation air system's measured performance collected during the benchmarking project. To be useful in identifying best practices, however, a more robust database involving facilities in several industries is necessary. Such information provides owners and designers with much needed comparison information.

Issue 2.1: Lack of energy benchmark data

Little data exists to compare high-tech facility systems' operation to their original design intent, or to best practices. Owners and designers need information to help identify efficient configurations, strategies, and technologies. Often there is a lack of instrumentation and monitoring equipment installed to be able to measure performance. There is also a lack of software tools available to organized measured data and facilitate analysis. There is no existing database of comparative information to aid the industries with high-tech buildings.

Possible actions:

- ♦ Develop and demonstrate a laboratory model based benchmarking tool to allow comparison of actual performance to a theoretical maximum.
- ♦ Benchmark energy use for key metrics to determine current operating ranges.
- ♦ Implement design intent tools for laboratories and cleanrooms to facilitate establishing and tracking energy use in key systems and components.

♦ Develop web based benchmarking database.

♦ Develop procedures and tools for self-benchmarking.

♦ Identify current best practices guidelines for key systems and components.

Time: short-term

Issue 2.2: Optimizing airflow

Airflow in high-tech buildings is frequently much greater than is needed to provide an environment suitable for safety and/or the process. Rules of thumb for recommended air change rates and containment velocities were established somewhat arbitrarily many years ago and have been widely adopted. Building operators do not know what airflow is optimal for their facility and often have a philosophy that more airflow is better even though there is no scientific basis for that assertion. Various measured air change rates for benchmarked facilities are shown in **Figure 7**. Complicating this, the airflow is often not known following initial balancing and it may be difficult to adjust airflow to desired values. Reducing airflow is a low-cost, high-value efficiency recommendation but a lack of knowledge is hindering implementation. In addition, industry rules of thumb have been adopted for issues such as fan face velocity, duct airflow velocity, cleanroom airflow, fume hood exhaust, etc. Sound scientific findings are needed to confirm or overcome the status quo.

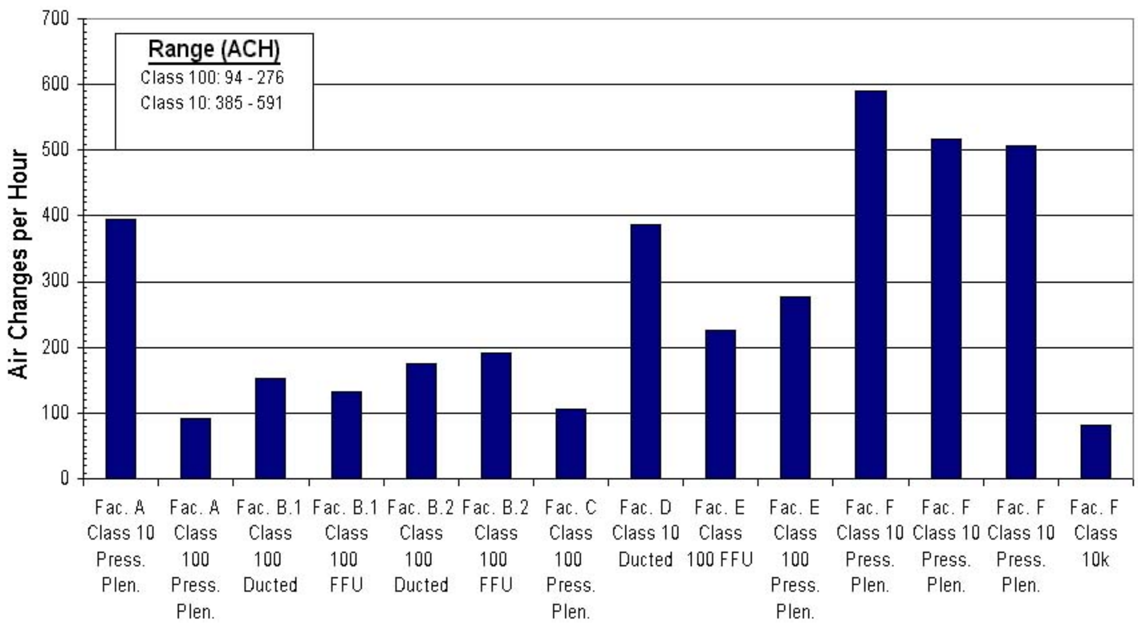


Figure 7. Air-change rate comparison.

Possible actions:

♦ Benchmark air systems' performance for a statistically significant number of cleanrooms for various cleanliness classes. Compare results to recommended ranges of airflow established by the Institute for Environmental Sciences and Technology, (IEST) and suitability for the process within the cleanroom.

♦ Use computational fluid dynamics (CFD) models and the physics of small particles to determine theoretical optimal airflow in cleanrooms. Validate results through particle counts during operation.

♦ Use CFD and physical models to establish a scientific basis for optimizing airflow in laboratories.

Time: long-term

Issue2.3: Identifying best practice

Cleanroom and laboratory HVAC systems' performance varies significantly due to a number of factors, such as overall resistance to airflow (pressure drop), efficiency of filters, fans, motors, etc., air change rates, etc. **Figure 8** shows wide variations in benchmark data for make-up air systems. Designers and owners lack comparative benchmark information to make informed choices for selection of the type of system, and components, which make up the system.

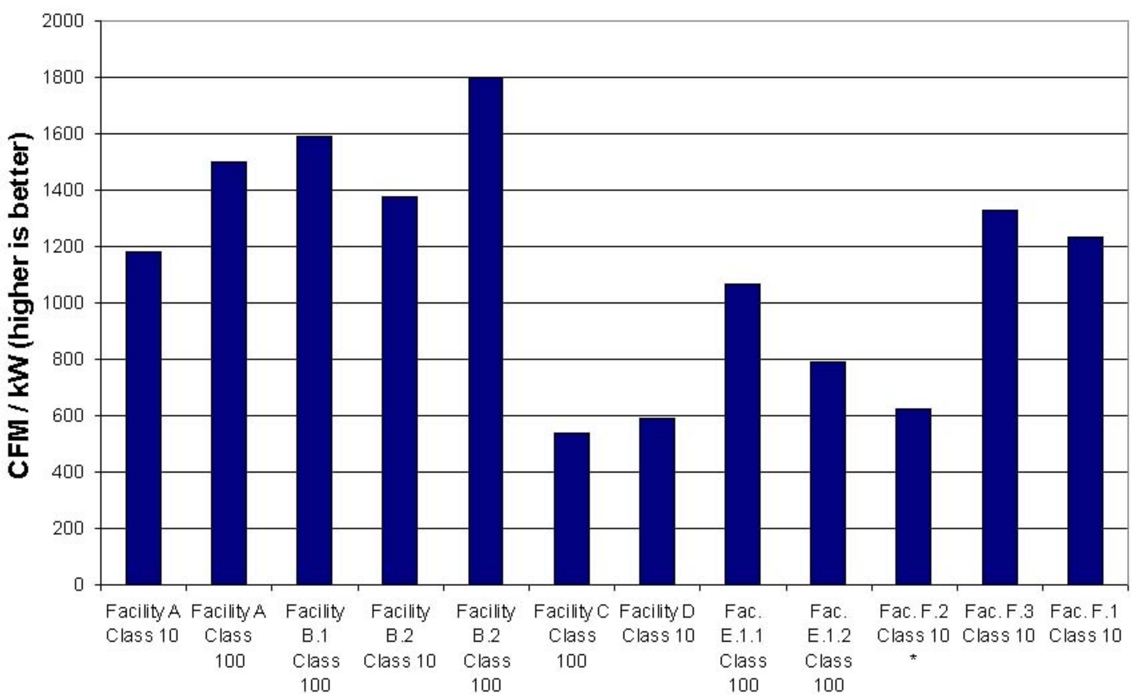


Figure 8. Make-up air comparison.

Possible actions:

♦ Obtain and utilize HVAC systems benchmark data to develop best-practice target values for key metrics in various configurations commonly used in laboratories and cleanrooms.

♦ Develop theoretical optimum performance of various types of systems and compare against actual measured performance.

♦ Develop design guidance addressing the relative energy efficiency of various system types and provide target metrics where appropriate.

Time: medium-term

Issue 2.4: Comparing energy efficiency

Energy efficiency comparisons are difficult to make due to lack of standard testing and reporting of energy performance for many specialize products used in high tech buildings. Industry would like to have information on performance, based upon consistent testing and reporting, to allow apples-to-apples comparison. Comparative energy use information similar to ENERGY STAR ratings would allow designers and owners to make informed choices through life cycle cost evaluations.

Possible actions:

- Develop a standard test procedure for fan-filter units.
- Develop a standard test and energy performance rating system for key system components.

Time: short-term

Issue2.5: Sustainable design criteria

Criteria are needed to judge the sustainability of high-tech buildings similar to the LEED rating system for office buildings (http://www.usgbc.org/). The current LEED criteria do not address the specialized needs of high-tech buildings. For example use of wood products in laboratories or cleanrooms would not be possible in most cases.

Possible actions:

- Develop a laboratory rating system.
- Develop a cleanroom rating system.

Time: medium-term

3. Planning, Design, and Analysis Tools

Planning, design, and analysis of high-tech buildings involves many complex decisions and a diversity of parties. This coupled with the fast-track design nature of many projects has fostered design shortcuts through use of rules of thumb or overly conservative assumptions, which often lead to energy inefficient systems. In addition, a comprehensive analysis of energy performance is difficult to impossible for the average facility engineer.

Issue 3.1: Research the design process

Research is needed into the design process for the design of high-tech buildings and how best to influence it. For example, research is needed into how design guides can be used, how to encourage use of energy design charrettes, and how building owners might evaluate alternatives based upon sustainability criteria.

Possible actions:

- ♦ Case studies involving observation of design teams in actual high-tech building projects to develop optimal learning tools.
- ♦ Participation in, and promotion of, energy design charrettes as a tool to disseminate energy efficiency ideas and technologies.
- ♦ Develop success stories to document successful use of sustainable technologies in high-tech facilities.

Time: medium-term

Issue 3.2: Develop energy simulation tools

Existing energy simulation tools fall short of adequately modeling high-tech spaces.

Possible actions:

- ♦ Develop tools for modeling and analyzing airflow, and energy analysis.
- ♦ Develop tool for modeling complex duct systems

Time: long-term

Issue 3.3: Develop design guides

Design guides are needed for the specialized issues for high-tech building systems. Programming (early design) guides can provide recommendations for achieving energy efficient systems through informed, timely decisions. Design guides for cleanrooms and laboratories can provide much needed guidance in achieving energy efficiency.

Possible actions:

- ♦ Trial use of LBNL Cleanroom Programming Guide and subsequently modify the guide to facilitate its use (Tschudi, W and T. Xu 2001).
- ♦ Development of a Cleanroom Design Guide—possibly in conjunction with ASHRAE's cleanroom technical committee.

Time: Short–medium term

Issue 3.4: Develop design intent tool

The high-tech facility owner's and designer's intentions are frequently lost or misinterpreted during the hand off from the design phase to the construction phase and further loss of information occurs going into operation. For high-tech buildings this information is extremely important for commissioning, operation, and maintenance. A tool to capture and track this information throughout the building life cycle is needed.

Possible actions:

- ♦ Trial use of the LBNL Laboratory Design Intent Tool and incorporate lessons learned.
- ♦ Develop a web-based design intent tool
- ♦ Expand existing laboratory design intent tool to include cleanroom facilities.

Time: short-term

4. Heating Ventilating and Air Conditioning (HVAC)

HVAC in high-tech buildings represents the highest energy load of any of the facility systems. Strategies and technologies to optimize HVAC systems have the largest potential for energy efficiency gains and usually have broad applicability.

Issue 4.1: Optimize ventilation airflow quantities

Airflow in high-tech buildings needs to be optimized to reduce overall energy loads. Research into methods of optimizing airflow systems and components is needed. This is apparent in the case of laboratory fume hoods and in airflow through cleanrooms.

Possible actions:

- ♦ Develop scientific basis for recommended or mandated airflow in cleanrooms and laboratories
- ♦ Develop alternatives to use of airflow as a containment or environmental control element.
- ♦ Develop methodology to optimize complex airflow

Time: long-term

Issue 4.2: Airflow distribution systems

Airflow distribution systems in complex high-tech buildings are not optimized. Issues such as pressure drop throughout the system, leakage and pressurization losses, layout, complex duct systems, push-pull systems, etc. are not optimized and represent a major challenge to a designer under tight schedule constraints.

Possible actions:

- ♦ Develop guidelines for design of low-pressure drop systems.
- ♦ Develop protocols for optimization of complex duct systems.
- ♦ Develop protocols for optimization of fume hoods
- ♦ Develop guidelines for air handler face velocity in high-tech buildings.
- ♦ Research concepts for low pressure drop fittings and components commonly used in air systems.

Time: long-term

Issue 4.3: Optimize chilled water systems

The efficiency of HVAC chilled water systems in high-tech facilities is rarely optimized and can be improved through a number of measures. **Figure 9** is a typical chiller used in a cleanroom application. The application of existing efficiency strategies, best practices, and "right-sizing" can

Figure 9. A typical chiller.

be effective in this area. In addition, strategies for staging cooling system operation, incremental build out, and optimizing water pumping and distribution can yield significant improvement.

Possible actions:

- ♦ Develop design guidance for optimizing chilled water systems.

Time: Medium-term

Issue 4.4: Scientific basis for recommended air change rates in cleanrooms

Cleanroom air recirculation systems operate continuously to control the cleanliness of the cleanroom environment. Recommended cleanroom air-change rates are established by IEST, a standards-setting body for cleanrooms. The flow rates, however, were selected based upon early operating experience in cleanrooms and not based upon scientific principles. Recent studies by Sematech and MIT, have confirmed that acceptable contamination control can be achieved using much lower airflows than current industry paradigms. Significant energy savings could be achieved if the industries that rely on cleanrooms for their production could decrease air changes (and required fan energy).

Airflow requirements are dependent upon many variables such as process contamination generation rates, make-up air, make-up air concentration, the filtration system efficiency, airflow distribution, etc. Airflow reduction and resulting energy efficiency improvement can be achieved if one or more of these factors assist in producing the desired contamination control. In absence of a sound technical basis for reduction, most cleanroom designers and operators will continue to utilize the IEST recommended high air change rates. Benchmarking (**Figure 7**) has confirmed that some cleanrooms operate at air change rates that even exceed IEST recommendations, with the philosophy that more air is better! A credible scientific basis for air change rates (or air velocity) is needed to justify more rational airflow resulting in large energy savings with relatively little capital cost.

Possible actions:

- ♦ Collaborate with IEST (and possibly ASHRAE) to establish a methodology to be used to establish scientifically determined airflow guidelines. The scientific studies would consider such issues as particle size, temperature and humidity effects, transport mechanisms, defect size, room obstructions, etc.
- ♦ Demonstrate that production is not affected by contamination release (of particles) in various locations in cleanrooms through use of computational fluid dynamics (CFD) models.
- ♦ Investigate use of alternative strategies, such as double HEPA filtration using lower airflow, or more ceiling filter coverage while maintaining or lowering airflow.
- ♦ Develop control systems to better detect the presence of particles in cleanrooms and control HVAC systems to provide only the air changes needed to maintain an environment suitable for production.

Time: Medium-long term

Issue 4.5: Develop efficient filters

Like other building types, high-tech buildings, especially cleanrooms, rely on filter systems to achieve appropriate cleanliness. Due to the large volumes of air transported in high-tech buildings, however, pressure drop through filters accounts for significant energy use. Air filters contribute to large pressure drops (resistance to airflow) and consequently require increased fan energy to move the required air. Research is needed to evaluate emerging new filtration technologies and to develop new, more efficient filtration schemes. Research may lead to discovery of new technologies that achieve the desired end result—a highly efficient contamination free workplace or environment.

Possible Actions:

- Evaluate state-of-the-art and emerging filter technologies through literature search and contact with researchers developing new filtration methods. Evaluate new filtration technologies for energy implications and other functionality.
- Research and develop new filtration methods.
- Research applicability of other related filtration technologies such as sterilization in hospitals; elimination of bio-terrorism threats; elimination of mold and dust mites, etc.

Time: Medium-long term

Issue 4.6: Reduction of airflow through fume hoods

Fume hoods in laboratories are responsible for the majority of the laboratory energy use. Lowering airflow (exhaust) through fume hoods will result in huge energy savings since the airflow through a typical fume hood accounts for approximately the energy of an average house. LBNL's high performance hood is under development through public goods funding. Development and deployment of the hood will lead to significant savings. Other related issues such as institutional barriers that specify minimum face velocity vs. levels of containment etc. are addressed elsewhere in this roadmap.

Figure 10. Berkeley hood.

Possible actions:

- Continue development of the Berkeley Hood (**Figure 10**). A discussion of the development needs is provided here: http://ateam.lbl.gov/hightech/fumehood/RD&DChallenges.html See a complete report on the status of the fume hood here: http://ateam.lbl.gov/hightech/fumehood/doc/LBNL-48983Print.pdf

5. Exhaust Devices

Optimizing exhaust flow to meet safety and efficiency goals can eliminate energy waste both in the exhaust system as well as in the energy used to supply and condition the make-up air. Establishing optimal exhaust rates and improving the efficiency of exhaust systems and devices represent opportunities for energy efficiency improvement.

Issue 5.1: Heat recovery

A large amount of heat is exhausted after being conditioned within laboratories and cleanrooms. While this waste heat represents an opportunity for heat recovery, there are difficult technical constraints due to the potential for hazardous or contaminated material in the exhaust stream. Technologies to recover the waste heat while maintaining strict safety separation are needed.

Possible actions:

- ♦ Research available heat recovery mechanisms for potential use in hazardous environments to eliminate cross contamination concerns.
- ♦ Develop new technology to recover waste heat

Time: long-term

Issue 5.2: Reduce exhaust in specialty equipment

Exhaust intensive components such as wet-benches and gas cabinets commonly used in cleanrooms and laboratories continuously exhaust large volumes of conditioned air. It is possible that improved containment of pollutants with reduced airflow can be achieved using technology similar to the Berkeley Hood developed by LBNL.

Possible actions:

- ♦ Research current operation and opportunity for exhaust reduction in gas cabinets and wet-benches.

Time: long-term

6. Controls and Monitoring

Issue 6.1: Improve monitoring capability

Most high-tech facilities lack adequate metering and monitoring capability to allow determination of operating efficiency.

Possible actions:

- ♦ Develop methodology, guidelines, and recommendations for metering different facility types to obtain energy end use and real time performance monitoring.

Time: Medium-term

Issue 6.2: Pollutant based control

The efficiency of air systems can be improved by controlling the flow based upon the presence and/or concentration of pollutants. Safety will be improved, and energy will be saved if the optimal amount of make-up air, recirculated air (in cleanrooms), or exhaust is provided. Ability to sense pollutant concentrations and increase or decrease the flow accordingly is needed. Airflow can be decreased for example if rooms are vacant or if no pollutants are present.

Possible actions:

- ♦ Develop control devices to monitor and adjust exhaust airflow to meet safe operating limits.
- ♦ Develop new methods to control laboratory airflow based upon concentration of pollutants.
- ♦ Develop new methods to control airflow in cleanrooms based upon particle counts (contamination) or human occupancy. (sometimes called demand-controlled ventilation).

Time: long-term

7. Information Technology for Enhanced Building Performance

Issue 7.1:

Building information systems using state of the art information technology such as wireless data acquisition, web-based controls and data monitoring, design intent and commissioning tools, and performance tracking tools are being developed for commercial buildings. Application of these technologies to the high-tech building market can yield immediate and substantial savings.

Possible actions:

- ♦ Develop demonstration projects by partnering with high-tech firms to demonstrate web-based data acquisition.

Time: Long-term

8. Mini-Environments

Use of mini-environments and other containment enclosures has potential to drastically reduce total energy consumption. By isolating a process in a small conditioned or ventilated space rather than an entire room, large savings in HVAC energy are possible.

Issue 8.1: Research opportunity for efficient enclosures

The energy saving potential for mini-environments and enclosures is not well understood. There is growing interest in semiconductor and pharmaceutical industries for use of these concepts however if large gains in energy efficiency can be demonstrated a significant market pull will lead to rapid efficiency gains. Further, there is opportunity to enhance and optimize the energy efficiency of the mini environments themselves.

Possible actions:

- Research and document whole building energy saving through use of mini-environments.
- Investigate energy efficiency opportunity and optimization within mini environments themselves.

Time: Medium-term

9. Lighting

Lighting in laboratories and cleanrooms represents a small fraction of the total energy use yet the efficiency and operational/productivity opportunities are many and should not be overlooked.

Issue 9.1: Improving lighting efficiency

Little attention has been placed on lighting efficiency in high tech buildings. The prevailing attitude is that constant high levels of lighting are required for the process occurring in the high-tech facility.

Possible actions:

- Implement lighting controls during unoccupied periods.
- Evaluate optimal lighting levels for various applications and reduce lighting level accordingly. (Mills and Borg, 1999
- Investigate use of task lighting in laboratories and cleanrooms.
- Develop new energy efficient lighting for cleanrooms. One such concept is to utilize a light pipe with the light source outside of the cleanroom (Mills et al, 1996). Another is to utilize fluorescent fixtures that do not have cathodes. Solutions that reduce maintenance required in cleanrooms will be attractive to the industry.
- Research use of daylighting in laboratories and cleanrooms through new light transmission technologies.

Time: Medium-term

10. Process Systems

A diversity of industries require clean environments for their manufacturing processes (**Figure 1**). Many varied processes occur in cleanrooms and each has unique requirements in terms of energy, safety, reliability, etc. In addition, given the diverse nature of process requirements, few widely applicable (cross-cutting) R&D opportunities exist in process improvements, however, there are common issues of load characterization and diversity, efficiency of process systems, and standby power reduction that should be improved.

Issue10.1: Right-sizing process electrical loads

Process electrical loads are difficult to accurately estimate for many industries that utilize cleanrooms and laboratories. Overly conservative load diversity (i.e., considering loads occurring continuously and simultaneously) and addition of unnecessary factors for uncertainty are key contributors to this problem. In addition, the process in the facility may change or be expanded over time making it even more difficult to initially size energy intensive building systems. The resulting oversized mechanical components often are inefficient and represent capital cost reduction opportunity.

Possible actions:

- ♦ Benchmarking to establish realistic range of energy intensity for similar processes.
- ♦ Perform studies to determine typical energy intensity growth in various industries.
- ♦ Develop design concepts and case studies to demonstrate methods to build out systems in an incremental fashion for optimal efficiency over the life cycle.

Time: Short-term

Issue 10.2: Reducing process equipment stand-by power

Process equipment frequently operates continually even if no processing is occurring. For many processes, development is needed to demonstrate that it is possible to place the equipment into "sleep mode". By working with process engineers many types of equipment could be placed in a reduced energy state without affecting the processing efficiency.

Possible actions:

- ♦ Demonstrate ability to place an energy intensive piece of process equipment into a sleep mode. Publicize case study to end users of the process equipment.

Time: Short-term

Issue 10.3 Consider power quality issues

Process systems often require "clean" power supplies and are susceptible to power quality issues. Care must be taken not to introduce power quality problems, which could affect process systems. "Power Quality Guidelines for Energy Efficient Device Application" prepared by EPRI for the California Energy Commission addresses issues to consider when applying energy efficiency technologies.

Possible actions:

- ♦ Perform case studies to investigate the effects on power quality for energy efficiency measures.

Time: Medium-term

11. Codes and Standards

Requirements for ventilation and/or containment in high-tech buildings with hazardous materials are established through building codes and standards promulgated by CALOSHA and others. Rules of thumb for high-tech building systems have evolved over time with little scientific basis. Many industry standards such as fume hood face velocity, and cleanroom recommended airflow are not based upon scientific rationale and could lead to significant savings and, in some cases, improved safety if relaxed.

Issue 11.1: Scientific basis rather than rules of thumb

The requirements for ventilation rates and face velocity of fume hoods, gas cabinets, and other specialty equipment have little scientific basis. In addition, these requirements may inhibit development of new, more energy efficient technology by creating unintended barriers (Bell et al 2001). Research is needed to establish sound technical basis to improve current practices and to develop criteria for evaluation of new technology such as developing containment based criteria and tests rather than relying on rules of thumb such as 100 ft/min face velocity in fume hoods.

Possible solutions:

- Research current codes and standards to identify minimum requirements for ventilation and their basis, if available.
- Work with industry associations, and codes and standards bodies, to get updated requirements incorporated based upon the research conducted. Following adoption of new requirements, disseminate information to designers and building owners.

Time: Long-term

12. Collaboration

Many organizations are stakeholders in improving efficiency in high-tech buildings. A strategic challenge in developing and implementing the roadmap is to collaborate with appropriate organizations—to maximize effectiveness, to avoid reinventing the wheel, to eliminate barriers, to prioritize activities, and to generate new ideas. Coordinating activities with the following organizations will enhance effectiveness and leverage the efforts of all:

- Industry Associations

  Sematech, Semi, ASHRAE, Silicon Valley Manufacturers Group, AMCA (Air Movement and Control Association International, Inc.), ISPE (International Society for Pharmaceutical Engineering), IDEMA (the trade association for the data storage industry), EPRI (Electric Power Research Institute), and others influence the efficiency of high-tech buildings.

- Industry Standards and Code Organizations

  IEST (Institute of Environmental Sciences and Technology), CAL/OSHA and US-OSHA, FM Global (Factory Mutual), ICBO (International Conference of Building Officials), and others set standards and thereby influence energy efficiency.

- Public Goods Sponsors and Associations

  In addition to the California Energy Commission, the following organizations either have sponsored research or are planning initiatives in this market: U.S. Department of Energy, U.S. Environmental Protection Agency, Pacific Gas and Electric Co., California Institute for Energy Efficiency, Southern California Edison Co., San Diego Gas and Electric Co., Northwest Energy Efficiency Alliance (NEEA), New York State Energy Research and Development Agency (NYSERDA), American Council for an Energy Efficient Economy (ACEEE), and others.

- Universities

  UC Berkeley, Arizona State University, Massachusetts Institute of Technology, Stanford University, Montana State University, and others have performed research in for this market.

- Industry Representation

  Partnerships directly with industries using or supplying products and services to high-tech buildings are necessary to provide insight into needed technologies, operational issues, and constraints. Access to complex, high tech facilities is critical to identify current opportunities and develop solutions. In addition, partnerships with high-tech suppliers to provide goods and services to advance research and development of new technologies has been, and will continue to be, an important factor in improving efficiency in this market. Architect/Engineers are also key partners in developing and introducing new technologies and strategies.

13. Market Transformation and Technology Transfer

Existing best practices and technologies, as well as future technologies need to be integrated more effectively, and delivery mechanisms need to be developed to reach the high-tech buildings vision. Market transformation and tech transfer strategies to reach designers, owners, and developers of these specialized building types need development.

The value of production in high-tech Buildings is high. Energy costs are a small component of production cost even though they may be the highest operating cost. Those in charge of production are often very change- and risk-averse and are wary of changes to facility systems that they perceive to be working well in support of production. In addition, return on investment criteria is typically too short to justify many energy efficiency measures even though (inefficient) systems remain in service for 20 years or more. A key challenge is to engage high-tech facility senior management—in part by developing life cycle cost models that convincingly make a case for energy efficient facilities. This approach coupled with promoting non-energy benefits is needed for this market.

A clear path to market is needed to bring products and strategies developed through California public interest research into widespread use. A key challenge therefore is to develop delivery mechanisms by working with industry and institutional end users and suppliers.

Existing industry organizations provide access to key industry people. Market transformation activities should target close collaboration with these organizations that are active in the target markets. Labs for the 21st Century, sponsored by U.S. Department of Energy's Federal Energy Management Program (FEMP) and U.S. Environmental Protection Agency is actively engaged with the laboratory community and offers numerous forums for information exchange. ASHRAE's laboratory and cleanroom technical committees also offer access to many key professionals. Organizations such as SEMITECH and IEST provide a similar large, diverse base of influential professionals.

Organizations concerned with high-tech facilities should be engaged to help promote new technology and to raise awareness of energy issues. Such organizations include:

Sematech	(www.sematech.org)
Semi	(www.semi.org)
ASHRAE	(www.ashrae.org)
Air Movement and Control Association	(www.amca.org)
Pacific Gas and Electric Company	(www.pge.com)
Industrial Technology Research Institute	(http://www.itri.org.tw/)
Institute of Environmental Sciences and Technology	(www.iest.org)
IDEMA	(www.idema.org)
International Society for Pharmaceutical Engineering	(www.ispe.org)
Northwest Energy Efficiency Alliance	(www.nwalliance.org)
Silicon Valley Manufacturers Group	(http://www.svmg.org/)
Labs for the 21st Century	(http://www.epa.gov/labs21century/about/index.htm)
U.S. Department of Health and Human Services, Food and Drug Administration	(http://www.fda.gov/)

Issue 13.1: Improve use of existing energy efficiency resources

There is a lack of knowledge and under-utilization of existing energy efficiency guidance in the high-tech building market. DOE crosscutting programs such as motor challenge, compressed air challenge, etc. and other efficiency guidance such as Pacific Gas and Electric's "Cool Tools" for chilled water systems are well developed and applicable to this market but are underutilized. Prior case studies and benchmarking have highlighted that this information is not reaching the target market.

Possible actions:

- Develop workshops and other outreach mechanisms. Include this information in presentations to targeted industry association meetings, technical committees, workshops, and trade publications.
- Develop case studies to demonstrate the applicability of generic information sources into high-tech facility systems.
- Training on use of existing laboratory design guides (LBNL and ASHRAE).
- Develop a guide to existing information accessible via the internet

Time: short-term

Summary and Priority of Issues

Through the workshops and survey input received, as well as prior research and energy benchmarking, the research and deployment needs and suggested actions were prioritized. Low priority activities were then dropped from the list. In general there is a high priority placed on most of the identified activities. Below is a summary of the needs and suggested actions along with their priority. A blackened cell in the table identifies the priority. Based upon these priorities, a progression of tasks was identified to begin work on the roadmap agenda. At a modest research level, many of the high priority tasks would stretch throughout the 10 year roadmap duration.

Summary and Priority of High-Tech Roadmap Issues

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
1. Understanding the Market				
1.1 Assessing the Market		■		
• Market assessment		■		
• Analysis of growth		■		
1.2 Decision-making	■			
• Building owner's motivation		■		
• Management case studies		■		
• Barriers identified in charrettes		■		
• Develop behavior model		■		
2. Benchmarking and Best Practices				
2.1 Lack of Benchmark Data		■		
• Develop and demonstrated model based benchmarking tool for labs.		■		
• Identify key metrics		■		
• Benchmark key systems and components		■		
• Utilize design intent tools		■		
• Develop web-based benchmarks		■		

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
• Develop self benchmarking protocols		■		
• Develop best practice guidelines		■		
2.2 Optimizing Airflow	■			
• Benchmark to IEST guidelines		■		
• Develop optimal cleanroom airflow values		■		
• Develop optimal airflow in labs		■		
2.3 Identify Best Practice		■		
• Develop best practice targets		■		
• Calculate and measure against theoretical best		■		
• Develop design guidance and performance metrics		■		
2.4 Comparing Energy Efficiency			■	
• Standard test procedure for fan-filter units (FFU's)		■		
• Standard reporting of other cleanroom system components		■		
2.5 Sustainable Design Criteria		■		
• Develop laboratory rating system		■		
• Develop cleanroom rating system		■		

3. Planning and Design Tools

3.1 Research The Design Process			■	
• Research design teams			■	
• Perform energy design charrettes			■	
• Develop sustainable success stories		■		
3.2 Develop Energy Simulation Tools		■		

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
• Develop modeling and analysis tools		■		
3.3 Design Guides for Labs and Cleanrooms			■	
• Trial use of cleanroom programming guide		■		
• Develop cleanroom design guide		■		
3.4 Design Intent Tools			■	
• Trial use of Lab design intent tool		■		
• Develop framework for cleanroom design intent tool		■		

4. Heating, Ventilating, and Air-Conditioning

4.1 Optimize Airflow	■			
• Develop scientific basis for recommended airflow	■			
• Develop alternatives for containment or environmental control		■		
• Develop methodology to optimize complex airflow		■		
4.2 Airflow Distribution Systems		■		
• Develop guidelines for design of low pressure drop systems		■		
• Develop protocols for optimizing complex duct systems		■		
• Develop air handler face velocity guidelines			■	
• Research low pressure drop concepts for fittings and components		■		
4.3 Optimize Chilled Water Systems		■		

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
• Develop design guidance for optimizing chilled water systems		■		
4.4 Cleanroom Air Change Rates	■			
• Develop methodology to scientifically determine recommended air change rates		■		
• Demonstrate particle settling through CFD modeling		■		
• Research alternative filtration strategies		■		
• Develop improved methods of detecting particles		■		
4.5 Develop Efficient Filters		■		
• Evaluate current and emerging filter technologies		■		
• Develop new filtration methods		■		
• Research application of related filtration technologies		■		

5.0 Exhaust Devices

5.1 Heat Recovery			■	
• Research available heat recovery options			■	
• Develop new heat recovery technology			■	
5.2 Reduce Exhaust In Specialty Equipment		■		
• Research exhaust opportunities in gas cabinets and wet-benches		■		

6. Controls and Monitoring

6.1 Improve Monitoring Capability			■	
• Develop metering guidelines		■		

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
6.2 Pollutant Based Control			■	
• Develop exhaust control devices			■	
• Develop new laboratory airflow control based upon pollutants		■		
• Develop new cleanroom airflow controls based upon contamination		■		

7. Information Technology for Enhanced Performance

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
7.1 Demonstration Of Use Of Information Technology			■	
• Demonstrate web-based data acquisition systems			■	

8. Mini-Environments

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
8.1 Research Efficiency Opportunity		■		
• Research whole building energy saving opportunity		■		
• Investigate energy efficiency of mini-environments		■		

9. Lighting

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
9.1 Improving Lighting Efficiency			■	
• Implement conventional lighting controls			■	
• Establish recommended lighting levels		■		
• Research task lighting options		■		
• Research efficient cleanroom lighting (such as light pipes)		■		

Item	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
• Research use of day lighting through light transmission technologies			■	
10. Process Systems				
10.1 “Right-Sizing” Process Loads	■			
• Industry benchmarks to establish real loads	■			
• Research energy intensity growth by industry		■		
• Develop concepts and case studies for efficient expansion		■		
10.2 Process Equipment Stand-By Power Reduction		■		
• Demonstrate “sleep mode” capability			■	
10.3 Consider Power Quality Issues			■	
• Perform case studies for power quality impact			■	
11. Codes and Standards				
11.1 Develop Scientific Basis To Replace Rules Of Thumb	■			
• Research current code and standards requirements	■			
• Develop science based ventilation recommendations	■			
• Collaborate with codes and standards bodies		■		
12. Collaboration				
12.1 Collaboration With Appropriate Organizations		■		

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
• Industry associations		■		
• Codes and standards bodies		■		
• Public goods sponsors		■		
• Universities		■		
• Industry partners		■		

13. Market Transformation and Tech Transfer

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
13.1 Improve Use Of Existing Efficiency Information	■			
• Hold workshops and other outreach	■			
• Develop case studies	■			
• Training on use of laboratory design guides	■			
• Guide to information on the internet		■		

Barriers

Workshop attendees and prior LBNL research identified a number of barriers to improving efficiency in high-tech buildings. These issues can be grouped into the following categories and were ranked by the workshop attendees to determine the most significant. The order of importance as ranked by the participants is:

Technical
Financial
Managerial
Operation
Legal
Environmental/safety
Regulatory
Market
Other

The most important categories of barriers identified by industry participants are discussed below in more detail:

Technical-Barriers Due to Lack of Knowledge:

Generally there is a lack of understanding of how to achieve efficiency improvements. This begins a lack of knowledge concerning the current operating efficiency. Even if the facility staff understands how efficiently they are operating, there is little data available to compare performance to others or to best practices. In the extreme, there is a feeling that energy is not a controllable cost. There has been a reluctance to share information concerning benchmark data or implementing best practices because this would in some way give away a competitive advantage. Compounding the problem is the lack of system monitoring capability. Many facilities have only a single electric meter for example, making it impossible to monitor at the sub-system level.

Where existing technical information is available for well-documented facility system issues such as chilled water, motor efficiency, compressor issues, etc. there is little awareness of available energy efficiency resources. Traditional barriers may also exist, such as difficulty in convincing management of the benefits and the ability to demonstrate return on investment for implementing new strategies however more exposure to this material by the high tech facility design and operations community is a logical first step.

Some criteria in common use have evolved without having sound scientific basis. Examples of such paradigms include:

- Air change rates in cleanrooms
- Face velocity in fume hoods and other containment devices
- Air handler face velocity
- Duct air velocity
- Ventilation rates for hazardous materials
- Cleanroom air velocity in Pharmaceutical plants
- Use of air showers

There is a need to establish sound scientific basis for key parameters important to energy use, safety, and production.

Financial Barriers

Industries are interested in return on investment. Many decisions as they relate to energy efficiency are governed by first cost or very short payback periods. This is true even though most equipment once installed continues to operate for 20 years or more. High-tech industries have little experience with life cycle cost evaluations when it comes to facility issues. Life cycle cost evaluation could provide the necessary justification for many efficiency measures, however, it is also possible that efficient design of some systems may actually lower first cost through right-sizing the equipment.

Another financial barrier is often created when budget responsibility for the facility construction is separately managed from the on-going operating budget.

Leased buildings may also introduce a barrier if the provisions of the lease make it difficult to modify systems for efficiency.

Managerial Barriers

Frequently, decision makers for cleanrooms and laboratories are not aware of the possibilities for energy saving. Decisions may be made based upon perceived benefits and risks without sound basis. Often the facility engineer cannot convince his management to make efficiency improvements for one of the following reasons:

- Lack of relevant financial or operating information
- Inability to analyze return on investment
- Process management and facility management have conflicting goals
- Different management approval chains
- Lack of time for proper evaluation
- Perceived risk to production

Operational Barriers

Continuous production and production reliability are usually the major driving force in high-tech buildings. Consequently, operational needs and priorities take precedence over facility needs in most cases. Inefficiencies in building systems are often overlooked in favor of maintaining production output or reliability. Efficiency improvements of building systems must enhance the reliability and output of the facility.

Regulatory Barriers

Where exhaust flow is mandated by code or other industry standards recognized by the local authority, other more efficient methods of contamination control or containment may be blocked pending a revision to the governing document. An example of this is with laboratory fume hoods where it is mandated to have 100 ft./min of face velocity, even if better containment can be provided with less flow. Another example is with pharmaceutical cleanrooms where room air velocity in cleanrooms is frequently 90 ft./min. because this is the value that the FDA has traditionally accepted without further extensive justification. Industry is reluctant to attack the accepted paradigm strictly for energy efficiency gains. However, it is likely that a scientific basis for a much lower airflow could be developed.

Appendix

Related Links:

Department of Energy related roadmaps
http://www.eren.doe.gov/buildings/technology_roadmaps/

Lawrence Berkeley National Laboratory, Cleanrooms website
http://eetd.lbl.gov/cleanrooms/

Lawrence Berkeley National Laboratory, Applications Team Web Site
http://ateam.lbl.gov/

Lawrence Berkeley National Laboratory, Laboratory Design Guide
http://ateam.lbl.gov/Design-Guide/index.html

Lawrence Berkeley National Laboratory, High Performance Fume Hood
http://ateam.lbl.gov/hightech/fumehood/fhood.html

Lawrence Berkeley National Laboratory, Cleanroom Benchmarking
http://ateam.lbl.gov/hightech/Cleanroom/Benchmarking/

International Technology Roadmap for Semiconductors 2001 Update;
http://public.itrs.net/Files/2001ITRS/Home.htm

Sematech Report: Exhaust Reduction in a 300 mm Tokyo Electron, Ltd. (TEL) Wet Station Using an Air Manager System (AMS); International SEMATECH Technology Transfer #01044114A-TR
http://www.sematech.org/public/docubase/document/4114atr.pdf

Northwest Energy Efficiency Alliance, Microelectronics Initiative progress report No. 1
http://www.nwalliance.org/resources/reports/89.pdf

Whole Building Design Guide
http://www.wbdg.org

High-Performance Commercial Buildings—A Technology Roadmap
http://www.eren.doe.gov/buildings/commercial_roadmap/

7/16/01 Workshop Attendees:

Cleanrooms-High Tech Buildings Roadmap

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