Title

High-Tech Means High-Efficiency: The Business Case for Energy Management in High-Tech Industries

Permalink

https://escholarship.org/uc/item/429064xw

Authors

Shamshoian, Gary
Blazek, Michele
Naughton, Phil
et al.

Publication Date

2005-11-15

High-Tech Means High-Efficiency:

The Business Case for Energy Management in High-Tech Industries

Gary Shamshoian	*Senior Mechanical Engineer* *Genentech*
Michele Blazek	*Director, Technology and Environment* *AT&T*
Phil Naughton	*Freescale Semiconductor Assignee* *SEMATECH*
Robert S. Seese	*Principal* *Critical Facility Associates*
Evan Mills	*Staff Scientist* *Lawrence Berkeley National Laboratory*
William Tschudi	*Staff Scientist* *Lawrence Berkeley National Laboratory*

November 17, 2005

This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. This work was sponsored in part by the California Energy Commission's Public Interest Energy Research Program (PIER). Helpful review comments were provided by Dale Sartor, Jon Livingston, and Bruce Nordman.

\

Introduction

In the race to apply new technologies in "high-tech" facilities such as data centers, laboratories, and cleanrooms, much emphasis has been placed on improving service, building capacity, and increasing speed. These facilities are socially and economically important, as part of the critical infrastructure for pharmaceuticals, electronics, communications, and many other sectors. With a singular focus on throughput, some important design issues can be overlooked, such as the energy efficiency of individual equipment (e.g., lasers, routers and switches) as well as the integration of high-tech equipment into the power distribution system and the building envelope. Among technology-based businesses, improving energy efficiency presents an often-untapped opportunity to increase profits, enhance process control, maximize asset value, improve the workplace environment, and manage a variety of business risks. Oddly enough, the adoption of energy efficiency improvements in this sector lags behind many others. As a result, billions of dollars are left on the table with each year of operation. Efficiency improvements thus translate not only into operating cost savings, but into improved product and service quality, competitive advantage and even earnings per share.

Energy inefficiency reflects organizational inefficiency. In the case of the high-tech sector, facility engineers are in the trenches identifying opportunities to improve energy productivity. These opportunities range from improving minor components to optimizing entire systems. However, a virtual cultural divide between these engineers and corporate decision makers can result in promising projects dying on the vine.

Staying on the cutting edge in one's core business requires maximizing energy productivity. Because industries that have high-tech facilities require particularly energy-intensive buildings that run 24/7, energy-efficient design and operation provides significant leverage to reduce overall operating costs. At the extreme, cleanrooms and high-density data centers can use up to 100-times as much energy per square foot as a typical office building (Figure 1), spending more than $1 million per month on energy.[1] Recent case studies for new construction show that some owners have saved a quarter or more of the facility's energy costs through efficient design strategies without increasing the project capital costs. Integrating energy efficiency throughout the design process has also yielded significant first cost savings for many projects. Also, capital and operating cost impacts must be considered in tandem in order to realize maximum value from facility improvements. In one of many real-world examples, thanks to improved heating, air-conditioning, and ventilation efficiency upgrades a major data center expanded computing power by 25% while keeping total facility energy use unchanged.[2,3]

---

[1] Naughton, P. 2001. "Energy Savings Turn into Cash-Flow Savings", *Semiconductor Fab Tech* (December)

[2] Blazek, M., H. Chong, W. Loh, and J.G. Koomey. 2004. "Data Centers Revisited: Assessment of the Energy Impact of Retrofits and Technology Trends in a High-Density Computing Facility," *Journal of Infrastructure Systems*, 10(3):98.

[3] The energy-efficiency measures included better optimization of power distribution units, power management modules, computer room air-conditioning units, alterations to operating conditions, facility-wide reductions in lighting, and improved facility controls. Additional savings can be achieved by improving efficiencies within the IT equipment network.

Historically, many of the business cases for the development of cleanrooms and other specialized high-tech facilities have focused on the revenue and capital costs of revenue-producing equipment. Operating expenses such as energy consumption and building related capital costs have been inadequately characterized, and their impact on the bottom line not well analyzed. In the case of power consumption, the fluctuation in price and other constraints are often unanticipated – particularly for peak periods. In some cases, risks and liabilities associated with power failure are clearly overestimated, resulting in the over-design of backup power systems. Also, risk-adverse choices in the backup power technologies with the emphasis on proven reliable technologies often result in missed opportunities for savings in capital and operating expenses.

There are a host of competitiveness-based reasons for pursuing energy efficiency. The operating costs to deliver products and services have been key to driving margins and influencing stock prices in high-tech corporations. With rising energy prices and increased power outages, in-house energy reliability improvements and energy management have assumed more strategic importance for upper management. Also important, a growing body of data shows that efficiency is associated with a healthier and higher quality work environment, especially regarding the use of outside make-up air.[4,5] On a life cycle basis, the energy consumption of high-tech systems can be the most significant source of environmental impacts.[6] For these reasons, energy efficiency is the keystone for the burgeoning sustainable/green-buildings movement, and broader trends towards corporate responsibility and leadership. Voluntary and mandatory programs (ranging from labeling schemes to building standards) are also driving the process. The Energy Star and LEED (Leadership in Energy and Environmental Design) labeling initiatives are the most well-known recognition programs. A complementary initiative -- The Laboratories for the 21st Century Program—defines best practices (Box 1).

The high-technology sector is often where innovation first occurs – its facilities are sometimes referred to as the “racecars” of the buildings sector, because new technologies and strategies to increase performance could trickle down to other building types. Yet, many lag behind typical buildings in terms of attention paid to energy efficiency. Changes in design practices can be challenging. The extreme criticality and high capital costs involved requires confidence in the facility procurement process. The “racecar” analogy must not result in increased chances of system failures: appropriate design practices must include risk analysis and redundancy for reliability enhancements.

---

[4] Placet, M., D. Winiarski, J. Heerwagen, S. Shankle, K. McMordie-Stoughton, K. Fowler, J. Hail, B. Liu, D. Hunt, D. Hostick, K. Poston, A. Walker, J. Harris, W. Tschudi, E. Mills, D. Zimmerman, J. Fiksel, and J. Toothaker. 2003. "The Business Case for Sustainable Design in Federal Facilities." U.S. Department of Energy, Federal Energy Management Program. http://eetd.lbl.gov/emills/PUBS/Sustainable_Federal_Bldgs.html

[5] Kats, G., A. Berman, J. Perlman, L. Alevantis, and E. Mills. 2003. "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force." Capital E, Washington D.C. http://eetd.lbl.gov/emills/PUBS/Green_Buildings.html

[6] Blazek, M, S. Rhodes, F. Kommomen and E. Weidman. 1999. “Tale of Two Cities: Environmental Life Cycle Assessment for Telecommunications Systems: Stockholm, Sweden and Sacramento, CA” *Proceedings of the International Symposium on Electronics and Environment*, IEEE, May 11-13, 1999.

Box 1: Laboratories for the 21st Century

Laboratory facilities represent an ever-expanding growth opportunity for advanced, environmentally preferred, building technologies. The typical laboratory uses far more energy and water per square foot than the typical office building due to intensive ventilation requirements and other health and safety concerns. Because the requirements of laboratory facilities differ so dramatically from those of other buildings, a clear need exists for an initiative exclusively targeting these facilities.

With this in mind, the U.S. Environmental Protection Agency and the U.S. Department of Energy established the Labs21 Program. It consists of three components:

* *Partnership Program*
* *Training and Education*
* *Tool Kit*

The primary guiding principle of the Labs21 program is that improving the energy efficiency and environmental performance of a laboratory requires examining the entire facility from a "whole building" perspective. Adopting this perspective allows laboratory owners to improve the efficiency of the entire facility, rather than focusing on specific laboratory components. As Labs21 participants understand, improving the efficiency of individual components without examining their relation to the entire system can eliminate opportunities to make other more significant efficiency improvements.

More about Labs21 can be found here: http://www.labs21century.gov

Industries of the Future Lean Heavily on Energy-Inefficient Practices of the Past

Applying entrenched design practices within a dynamic marketplace with rising utility costs will not produce facilities of maximum life-cycle value. In many cases, older buildings are often retrofitted for high-tech uses without evaluating actual functional needs and resulting changes to power requirements. Emerging technologies and thoughtful design and operation can yield very substantial reductions in energy operating costs.

This is the conclusion of a growing body of energy benchmarking studies. For data centers, we have seen a factor of 10:1 variation in energy intensity per unit floor area (Figure 2) and a 2:1 variation in the effectiveness of the HVAC system (Figure 3). The ratios for labs and cleanrooms are 7:1 and 20:1, respectively (Figures 4-5). In the latter case, the savings potential for a single mid-sized cleanroom is $400,000 per year. The most efficient of these buildings do not represent the full potential; best practices would result in even higher performance.

Opportunities abound, whether discussing individual pieces of equipment, sub-systems, or entire facilities. Among a myriad of examples:

- We have noted a five-fold variation in the efficiency of cleanroom fan-filter units (FFUs) on the market today,[7] and a similar range in the energy-intensity associated with lighting.

- We have observed a seven-fold variability in the part-load efficiency of cleanroom chillers. It is telling that a chiller in a cleanroom can use $300,000 in energy each year (equal to its first cost!), and yet they are typically not monitored or optimized.

- Avoidable energy costs often stem from sub-optimal facility operation. Simultaneous heating and cooling and/or humidification and dehumidification, for example, are strikingly common problems, often corrected through commissioning efforts.

These examples focus on the building environmental infrastructure. The systems within the buildings can also be made more efficient. For example, analyses show that improving mediocre server power supply efficiencies of 70% towards 95% yields a net present value in energy savings that will exceed the equipment's purchase price. This translates into an energy savings potential of up to $1.5 million/year for one data center evaluated (Figure 6).

The Key to Energy-Efficient Design – Systems Analysis

The challenge and opportunity of energy efficiency extends beyond swapping in and out individual components. Most of the gold to be mined is found at what can be thought of as the "systems level". Implementing efficient components is often a "one-handed clap", as they under-perform if not properly controlled and integrated with other components in the facility. Sometimes the opportunities are far from glamorous: e.g., duct and piping systems that have low-friction elbows or use high-quality filters facilitate flow and translate into high pumping and fan efficiencies or simply rearranging server racks so that the hot exhaust of a server is not the intake for another already overheated one. It is not enough for pumps and fans to be "efficient": their potential savings is optimized with system integration enabling small improvements can yield large benefits. Other strategies are glamorous, yet simple. Flat panel displays use significantly less energy than CRTs, emit less heat, allow for downsizing of central chiller plants, and are preferred by most employees.

A case in point: A major biotech firm recently designed a new five-story facility. The building emphasizes natural lighting and materials, including a shaded top floor deck and promenade on each floor's southern exposure. High-performance glazing, flat screen computers, low-pressure-drop HVAC design, and efficient right-sized lighting systems

---

[7] Jeng, Ming-Shan, T. Xu, and Chao-Ho Lan. 2004. "Toward Green Systems for Cleanrooms: Energy Efficient Fan Filter Units." *Proceedings of SEMI Technology Symposium: Innovations in Semiconductor Manufacturing*, SEMICON West 2004. San Francisco (July) pp 73-77. LBNL-55039. http://hightech.lbl.gov/Documents/LBNL55039_TXu.pdf

resulted in a 20% reduction of the mechanical heating and cooling system size (a process we call "right-sizing"). The facility used three air-conditioning units for two perimeter zones and one interior, and the resultant duct sizing allowed them to lower the overall building height by 2.5 feet, for significant construction cost savings. The reduced building size and subsequent reduction of perimeter exposure to environmental heat loads led to additional HVAC peak capacity reductions. The cumulative, HVAC capacity savings reduced the sizing of the back-up generator, resulting in additional first-costs savings. These construction cost savings exceeded the added first costs of improved glazing to save the project approximately 1.5% of total construction costs (worth approximately $400,000). The building is expected to perform about 18% better than the efficiency levels mandated by the California energy efficiency standards (some of the most stringent in the country), saving $17,000 each year in heating, ventilation, and air-conditioning costs). The project qualified for a rebate from the local utility. The facility provides a good indoor environment for workers, who also appreciate working in a sustainably designed building. The resultant system-sizing benchmarks set the standard for similar cost savings and efficiency improvements in future projects. As its profits are driven by the creativity of its employees, personal productivity improvements may be the greatest benefit of this integrated design effort. Sustainable buildings can be better places to work, which translates into better morale, lower absenteeism, and reduced turnover.

Increasingly complex and powerful automation and control systems enable particular system-level energy savings opportunities. Be it lights that are turned off when not needed, or variable-speed fans that only need to run at full speed three hours per month, better control can save enormous amounts of energy while ensuring that adequate building services are available when demanded. The non-energy benefits of controls are numerous; recently it has been found that buildings with more advanced ventilation control systems are more resistant to chemical and biological attacks.[8] Also, the use of outside air can improve the overall air quality for the occupants in the building.

Some controls-based strategies must be implemented by component manufacturers, rather than by on-site facility engineers. For example, the great majority of servers are operated at very low percentages of their computing capacity the great majority of the time. However, today's servers vary in power consumption very little as the computing use ranges from idle to completely busy. This is akin to a car using the same amount of gasoline idling at a stop sign as when maximally accelerating. Some new servers reduce their power consumption (to varying degrees) as the amount of needed computing drops. The energy savings from this technique are large.

Systems-level considerations extend beyond facility mechanical systems. An enormous opportunity in data centers is to rethink the tradition of multiple power supplies and AC-DC conversions, each of which introduces multiplicative inefficiencies and generates waste heat. The macro-level potential is significant: IT equipment consumes about $8 billion/year of energy in the US alone. A single high-powered rack consumes enough energy to power a hybrid car across the United States 337 times. The irony is that many of the data centers are co-located with traditional telephone technologies that routinely

---

[8] See http://securebuildings.lbl.gov/

use DC power plants and consequently improve efficiency, increase backup power capacity, and filter signals to improve power quality.

A new generation of emerging technologies offer further opportunities to capture component- and systems-level efficiency gains (Box 2).

“Rules of Thumb” can be “All Thumbs”

One of the ways in which inefficiency becomes institutionalized in both design and operation is the unquestioning perpetuation of certain “rules of thumb”. For example, decades ago, through an unscientific process, it was deemed that air should flow into laboratory fume hoods (and other “containment devices such as gas cabinets) at 100 feet per minute (the so-called “face velocity”). This is one of the reasons that a single fume hood uses nearly four-times as much energy as a typical home.[9] Field measurements, however, have shown that slower speeds can maintain or even improve safety (by reducing the risk of undesirable turbulence in the hood opening), and, of course, save large amounts of energy in the process.

There are similar forms of “conventional wisdom” regarding cleanroom air recirculation rates. The purpose of cleanroom air movement is to control contaminants and minimize product defects. Boosting the airflow is not the best way to do this, since it increases turbulence-induced contamination risks while consuming significantly more energy. Benchmarking studies have shown that some cleanrooms provide over six-times the air-change rates of others within the same cleanliness classification, resulting in significant capital and operating cost impacts (Figure 7). An emerging strategy—demand-controlled filtration—uses direct measurements of contaminants to determine air-circulation rates. Case studies have demonstrated 60-80% energy savings during periods when airflow is reduced. A savings potential of $138,000/year was estimated to be obtainable simply by lowering air circulation rates when the cleanrooms are not occupied – an essentially no-cost measure.[10] In such cases, raising energy efficiency and improving process control go hand in hand.

The systematic over-sizing of utility systems and the resulting oversized cooling equipment is a pervasive problem that typically results from overestimating electrical demands thereby creating fictitious sources of heat within a facility. Over-sizing is often aggravated by outrageous claims of power density and combined with overestimates of industry growth. This is compounded by the aggregate impact of multiple disciplines (owners, process engineers, electrical engineers, HVAC engineers, etc.) each adding

---

[9] Mills, E. and D. Sartor. 2004. "Energy Use and Savings Potential for Laboratory Fume Hoods." *Energy*, 30:1859-1864. LBNL-55400. http://eetd.lbl.gov/emills/PUBS/Fume_Hood_Energy.html

[10] Tschudi, W.T., D. Faulkner, and A. Hebert. 2005. “Energy Efficiency Strategies for Cleanrooms Without Compromising Environmental Conditions.” *ASHRAE Transactions* (in preparation).

Box 2: What's in the R&D Pipeline?

The energy consumed by high-tech industries and institutions represents an attractive and often untapped opportunity for energy savings. R&D sponsored by the U.S. Department Of Energy, U.S. Environmental Protection Agency, New York State Energy Research and Development Authority, the California Energy Commission's Public Interest Energy Research Program, and others have included benchmarking energy performance and the development of technologies, tools and strategies for addressing various aspects of the overall efficiency opportunity for this market. Much has been accomplished, yet further development will enable these buildings to fully reach their energy savings potential. While improving each piece of the efficiency puzzle provides important gains, an integrated approach has the potential for 30-50% further improvement beyond current best practices. Examples include:

- *The primary energy service provided in cleanrooms is the control of particles in the space. The question of whether higher levels of ventilation necessarily yield higher levels of particle control has not been adequately addressed. New technologies will exploit the potential for dynamically managing ventilation rates in response to real-time particle-count measurements. With demand-controlled filtration, desired environmental conditions can be maintained without excessive energy use. The results of a recent field study were very positive, indicating an economic payback time of 1 to 4 years, depending on whether or not the facility's ventilation system is already equipped with a variable speed drive.*

- *Fan filter units (FFUs) are increasingly used in contamination control environments such as cleanrooms. They consist of a small fan, controller, and a filter enclosed in a box, and maintain specific airflow. However, there is no standard procedure of measuring FFU performance or energy use, which presents an obstacle for users want to specify or purchase efficient models. A new standardized method will soon be available, and has shown that efficiencies of products now on the market vary by a factor of three.*

- *Power supplies convert high voltage AC power into the low voltage DC power needed by the circuitry found within servers, routers, hubs, switches, data storage units, and other electronic equipment used in data centers. Typical server power supplies operate at roughly 65% to 75% efficiency, meaning that 25 to 35% of all the energy consumed by servers is wasted (converted to heat) within their power supplies. The technology exists to achieve efficiencies of 80% to 90% in conventional server power supplies. Even greater efficiencies might be possible by systematically replacing the chain of AC power generation, AC-DC-AC uninterruptible power supplies, and AC-DC power supplies with a direct DC power system in data centers. Efforts are underway to demonstrate and commercialize these innovations.*

- *Backup power systems are essential for mission-critical facilities, yet while in standby mode their energy use can be unnecessarily high. Efficiency losses in uninterruptible power supplies (UPSs) represent about 5% to 12% of the energy consumed in data centers. Manufacturer specifications can differ widely from measured results because of differences in loading conditions and test procedures. New cost-of-ownership tools will enable facility owners to make better technology purchasing decisions.*

- *A new generation of software tools are being developed that enable facility designers and operators to evaluate the technical and economic potential for new technologies.*

For more information, see: http://hightech.lbl.gov "safety factors" to their sizing calculations, often unaware that others in the decision chain have already done so. The result is not only systems that have much higher first cost than they should, but also higher operating costs due to excessive and inefficient on-off cycling and/or part-load operation.

Erroneous conventional wisdom can also lead to avoidable obstacles in citing facilities and gaining utility service. Conventional wisdom has been that data centers can require an electrical grid connection to support 250 (or more) watts per square foot of space. Our benchmarking results of 14 conventional data centers found an average value of 25 watts in practice, and a maximum value of about 65 watts (Figure 2). A larger survey by the Uptime Institute came to nearly identical results.

Energy Efficiency is the Tip of the Iceberg

High-energy-performance facilities also tend to accrue considerable non-energy benefits, such as superior safety, risk management, improved process control, and maximized up-time. These are rarely included in lifecycle cost analyses and associated decision making.

- I**mproved Productivity:** Many labs have a need to add fume-hood work stations but don't have available air supply or exhaust capacity. Emerging high-performance hoods (with lower face velocities that maintain or improve safety) will allow the replacement of one conventional hood with two new hoods (Figure 8).[11] This will avoid very high cash outlays for increasing mechanical heating and cooling capacity (often so expensive that it is not done) and significant lab downtime. The benefits in terms of greater productivity or output, will dwarf the (still significant) energy costs savings (several thousand dollars per hood per year) generated by the more efficient hoods.

- **Improved Process Control:** Minienvironments improve environmental control in cleanrooms, and are only now being assessed for their value in reducing energy costs (Figure 9).[12] Driven by quality control benefits (smaller space without human occupancy), enormous energy savings can also result from no longer needing to eliminate all particles from enormous "ballroom" areas. The use of minienvironments in the latest wafer fabs and the benefits associated with a focused environmental control has resulted in significant reductions in air recirculation rates, decreases in the order of greater than 35% are quite common. As noted in an earlier example, the energy efficiency strategy also leads to process improvement.

  In data centers, some analysts have observed that proximity of fans to computer drives increases the numbers of rewrites/retries (eroding productivity). Alternative

---

[11] Bell, G., D. Sartor, and E. Mills. 2001. "Development and Commercialization of a High-Performance Laboratory Fume Hood." LBNL-48983 (rev.). http://eetd.lbl.gov/EMills/PUBS/BerkeleyHood.html

[12] Xu, T. 2005. "Investigating the Performance of a Minienvironment System." Presentation at Contamination Control Technical Session, The 51st ESTECH Conference May 1-4, 2005, Hyatt Regency Woodfield, Schaumburg, Illinois, The Institute of Environmental Sciences and Technology (IEST). Technical paper published in the Proceedings of The 51st ESTECH Conference.

cooling strategies now in the R&D phase may eliminate these fans altogether. Another benefit of doing so is to reduce the rising problem of fan noise in server farms.

Excessive heat—a direct outcome of energy inefficiency—has become a limiting factor in the number of servers (productivity) that data centers can house. Efficient power supplies can yield about $3000/year/rack in energy savings and allow about 20% more servers per rack.[13] Configuration matters!

- **Enhanced Reliability:** In the context of data centers, eliminating un-necessary AC-DC conversions not only saves energy but eliminates devices that can fail. When using outside air when adequate for cooling (also known as "free cooling"), the mechanical compressor effectively becomes a backup system that can be used to augment or replace the primary system.

  Backup power systems are often essential, yet rarely optimized. In some cases, their implementation is limited due to hesitance to try new technologies (e.g., flywheels or fuel cells) or dictated by customer requirements (some web-hosting facilities have dedicated diesel generators for customers). While not a panacea, energy-storage flywheels are more efficient and compact than standard uninterruptible power supplies (UPS), thereby reducing floor space requirements, associated construction costs, and they can be 20% more efficient than battery back-up systems.

- **Reduced O&M Costs:** Full-throttle operation is often designed into a project, even though it is not needed. As one of many examples, applying variable-speed controls to traditionally constant-volume air- or fluid-movement applications can enhance performance and increase system flexibility while saving energy. The added benefits of reducing operational challenges, extending equipment life, increasing diagnostic capabilities, and minimizing downtime during modifications often eclipse the direct energy savings benefits.

Extended-area filters in cleanroom ventilation systems save energy (by reducing the pressure drop) but also reduce maintenance shutdowns, as they need to be replaced less often, and reduce filter purchase and waste disposal costs. When integrated properly, lower system pressure drops lead to less horsepower requirements and overall project first cost savings.

Quality Assurance Includes Energy Efficiency

Quality assurance (e.g. design intent documentation, commissioning, diagnostics) is essential to ensuring that new projects go smoothly and to maintaining energy performance after facility start-up. As buildings become more complex, the need for

---

[13] Calwell, C. and B. Griffith. 2005. "Enabling High Efficiency Power Supplies for Servers: Update on industry, government and utility initiatives." Presented at the *Intel Developer Forum*. Cited benefits correspond to a change from 70% to 83% efficiency.

quality assurance only increases. In one example, an efficient chiller was installed in a cleanroom. Shortly after installation, an additional 50% energy savings was achieved by (properly) resetting the variable speed controls. At another site, QA studies found that a $1,000,000 chiller called for in a plant expansion was entirely un-necessary.

A recent analysis of efforts to identify energy-related performance problems found about 20% whole-building energy savings ($3.60 per square foot annual savings, averaged across the sample) were achieved with an 5-month payback time.[14] These results were significantly better than observed in other building types, such as office buildings. Non-energy benefits included early identification of maintenance problems, safety issues, avoiding premature equipment failure, etc. In addition to verifying proper system operation and fulfilling user requirements, commissioning ensures that problems get fixed during warranty and additional first-cost savings can be achieved by reducing callbacks or avoiding litigation over construction defects. In “mission-critical” facilities, commissioning demonstrates the ability of the building to perform at the extremes of its design intent, and “flushes out” problems that could later result in costly downtime. When performed during design and construction, first-cost savings typically more than pay for the cost of commissioning; the energy savings are icing on the cake.

Many high-tech industries have now included road maps for improvements in their energy efficiency as part of their ISO 14001 Environmental management Systems. These forward seeing companies have realized not only benefits to themselves but also the benefits to their corporate citizenship goals.

Greening the Bottom Line

While the productivity benefits we’ve cited can be difficult to quantify, energy savings alone can easily reduce total costs of ownership. Many capital efficiency improvements can be made that yield an annualized return on investment of 50% to 100%.

Recent energy retrofits of 36 data centers yielded an aggregate energy savings of $2 million/year with an average payback time of under three months (Figure 10). Motorola has similarly observed payback times of even less than one month, without capital investment (labor only), and overall savings of $5 million/year across a portfolio of projects – translating into real reductions in wafer costs.[15]

Labor-based quality assurance measures have low costs, but can yield large savings. In new construction there can be immediate positive cash flow, thanks to first-cost savings achieved by using a systems approach and right-sizing. Benefits can thus accrue to both operating and capital budgets.[16]

---

[14] Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M.A. Piette. 2004. "The Cost-Effectiveness of Commercial-Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States." Lawrence Berkeley National Laboratory Report No.56637 http://eetd.lbl.gov/emills/PUBS/Cx-Costs-Benefits.html

[15] Naughton (2001), *op cit.*

[16] Naughton (2001), *op cit.*

Energy efficiency also makes sense in terms of financial asset management.[17] Property values are a function of net operating income (the difference between gross income and expenses). As a major expense item, any reduction in energy costs translates into increased value of the real estate asset. Valuations vary depending on markets and market conditions, but capitalization rates of 5% to 10% are common. Since property value equals net operating income (NOI = gross income – pretax expenses) divided by CAP rate, a dollar of energy savings translates into $10 to $20 in increased resale value. An additional dimension is the hedging benefit of a property that is less vulnerable to energy price shocks, i.e. lower overall energy use translates into a smaller shock to bottom-line operating expenses in the event of abrupt price increases. Additional benefits can be captured by pursuing a broader "green buildings" design strategy.[18]

However, energy efficiency improvements must thus compete with other capital investments that often yield payback times of less than one year; a much higher hurdle than faced by faced by energy efficiency in other sectors. As a case in point, a recent data center retrofit proposal that would have yielded $264,000/year in energy savings with a 2.7-year payback time was rejected as uncompetitive with other options (e.g., buying better switches).

Where There's a Will, There's an (Efficient) Way: Towards Best Practices

It is often asked: "If energy efficiency is so profitable, then why isn't it already being done"? In an ideal world, it would be. But, in practice there are barriers. Cross-cutting barriers include generic resistance to change and that the "mission-critical" nature of the processes in high-tech industries has been misconstrued as a reason to pass over programs that address energy efficiency. Specific barriers include the separation between capital and operating budgets, differences in incentives for owners and tenants, lack of trained staff, fragmentation among the many trades that must interact to create and maintain facilities, "value engineering" processes in new construction that result in hasty cuts to valuable efficiency design features in the name of first-cost savings, and, perceived risks that may not be in fact material. If improperly applied, efficiency strategies could have adverse impacts on uptime; yet the opposite has also shown to be true if good design practices are followed. Time to market is another key factor: energy efficiency upgrades can be seen as undesirable if they prolong facility construction or renovation time. If all of these barriers are swept aside, accounting disincentives may remain, e.g. wherein lagged historically-based internal utility recharges effectively dilute the savings attributed to a specific production unit that may have implemented an effective savings program.

---

[17] Mills, E. 2004. "Amplifying Real Estate Value through Energy & Water Management: From ESCO to 'Energy Services Partner'". *Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar, CA August 22-27. LBNL-52768. http://eetd.lbl.gov/emills/PUBS/EnergyServicesPartners.html

[18] U.S. Green Buildings Council. N/D. "Making The Business Case for High Performance Green Buildings." USGBC, Washington, DC., 12 pp.

The reasons for the lack of attention to this issue are numerous, but there are two drivers that have resulted in systematic inefficiencies: inadequate backup power configurations and overestimates of power requirements for such buildings. As counterintuitive as it may seem, the most innovative industries can be the most reluctant to try new ideas when it comes to energy management.

Below, we provide a generalized framework for institutionalizing best practices. Excellent resources are available to help an organization move forward.

- Institute an energy management program, integrated with other functions (risk management, cost control, quality assurance, employee recognition, training). Use life-cycle cost analysis as a decision-making tool, including energy price volatility and non-energy benefits (e.g. reliability, environmental impacts).
- Create design intent documents[19] to help involve all key stakeholders, reduce risks of client dissatisfaction, and keep the team on the same page, while clarifying and preserving key the rationale for key design decisions.
- Adopt quantifiable voluntary goals based on Best Practices
- Minimize construction and operating costs by introducing energy optimization at the earliest phases of design; avoid excessive/redundant “safety margins” and right-size to trim first costs.
- Include integrated monitoring, measuring and controls (Building Management System – BMS) in the facility design.
- Benchmark existing facilities, track performance, and assess opportunities.
- Incorporate a comprehensive commissioning (quality assurance) process into new construction and retrofit projects.
- Include periodic “re-commissioning” in the overall facility maintenance program.
- Evaluate the potential for on-site power generation, including combined heat and power technologies.
- Ensure that all facility operations staff are provided with site-specific training that includes identification and proper operation of energy-efficiency features.

At several levels, energy efficiency can be thought of as a form of risk management. Of course, it manages the risks and uncertainties of future energy price increases by reducing the amount of various energy commodities consumed. More importantly, the types of quality assurance described above mitigate performance risks, help ensure a safe, comfortable, and healthy indoor environment, and can prevent business interruptions by proactively detecting and remedying performance problems or increasing the ability for a facility to run on on-site power in the event of supply disruptions from the power grid.

Enterprise-wide success requires a marriage of the bottom-up ingenuity and motivation among engineering staff with top-down vision and guidance of upper management. The best practices offered in this article provide a starting point for closing this gap.

---

[19] Mills, E., D. Abell, G. Bell, J. Faludi, S. Greenberg, R. Hitchcock, M.A. Piette, D. Sartor, and K. Stum. 2002. "Design Intent Tool: User Guide." LBNL/PUB-3167. http://eetd.lbl.gov/emills/PUBS/Design_Intent_Tool.html

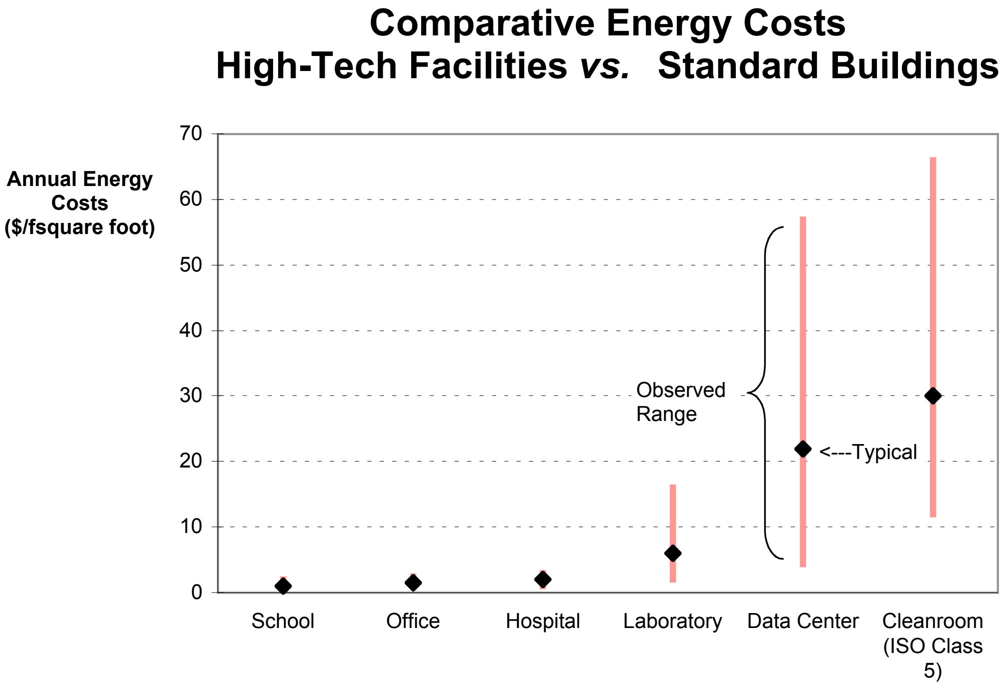

Figure 1. Comparison of energy costs for high-tech buildings and conventional building types. Schools, Offices, and Hospitals from USDOE/EIA Commercial Buildings Energy Consumption Survey (1999 values). High-Tech buildings from LBNL benchmarking databases. Cleanrooms with the highest cleanliness standards can use significantly more energy than those shown.

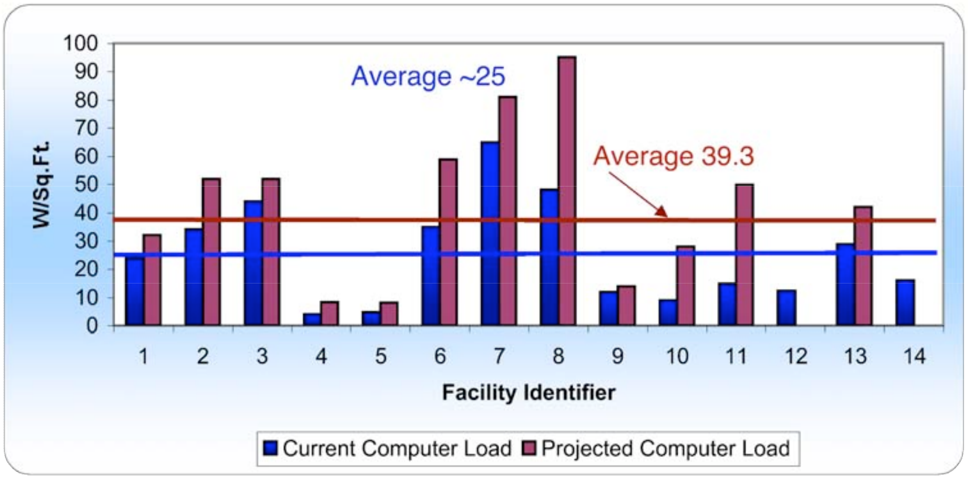

Figure 2. Benchmarking results for 14 data centers showing total power requirement per unit floor area for as-is conditions and if server racks were fully loaded. Source: LBNL benchmarking database.

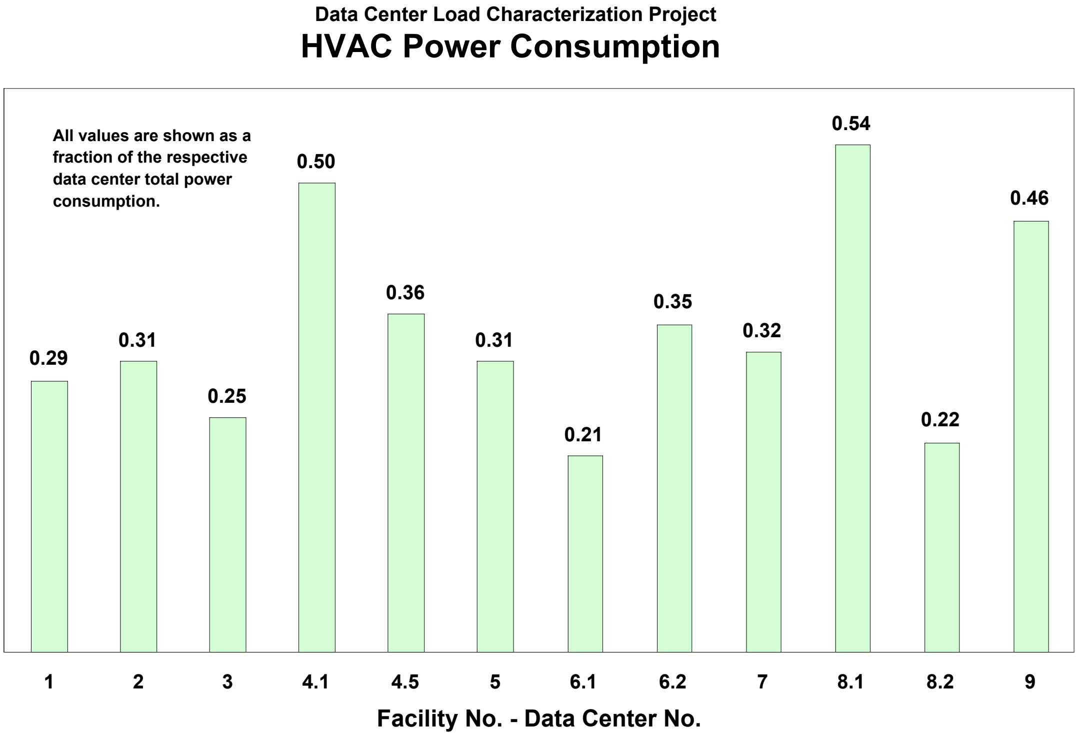

Figure 3. HVAC effectiveness. Heating, ventilating, and air-conditioning costs can vary from about 20% to 55% of total energy costs in data centers, a sign of hidden inefficiencies. Source: LBNL benchmarking database.

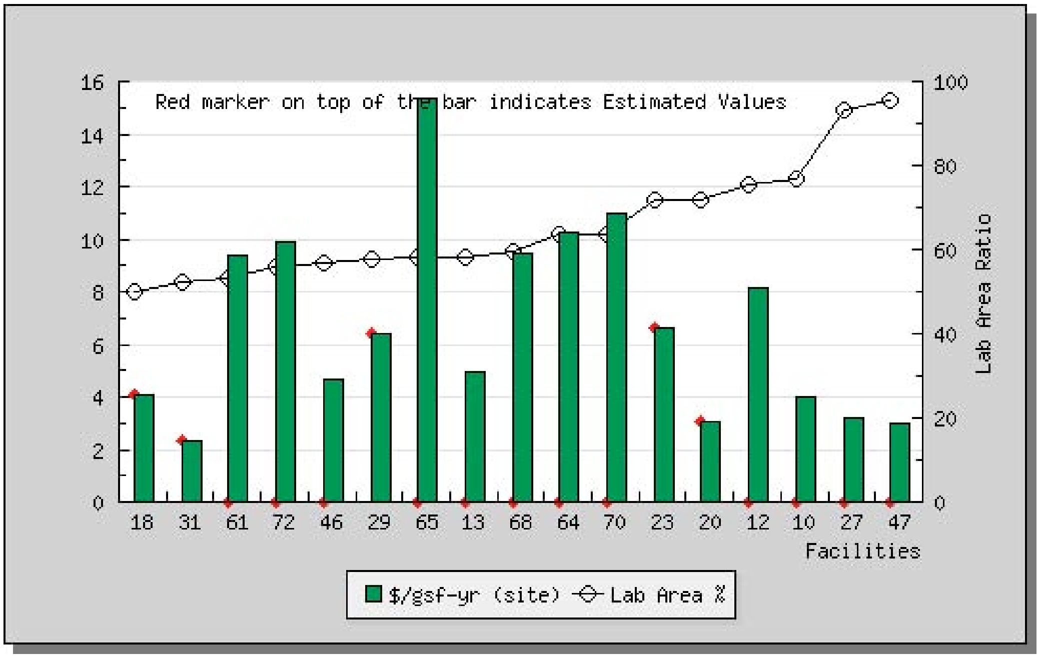

Figure 4. Normalized annual energy costs in laboratories (facilities with >50% of total floor area in labs). Source: LBNL benchmarking database.

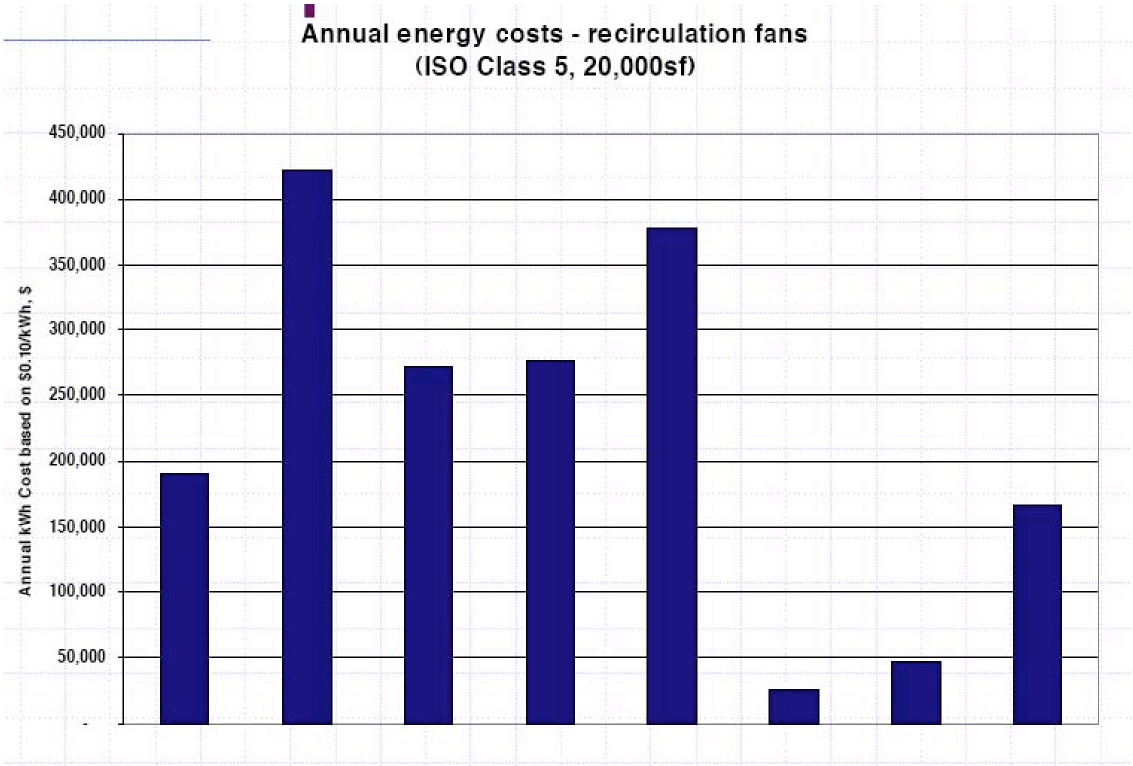

Figure 5. Measured cleanroom energy costs associated with air recirculation. Note that costs for rooms with similar levels of contamination control ("ISO Class 5") exhibit a factor of nearly 20 in energy costs. Each bar corresponds to an individual cleanroom. Source: LBNL benchmarking database.

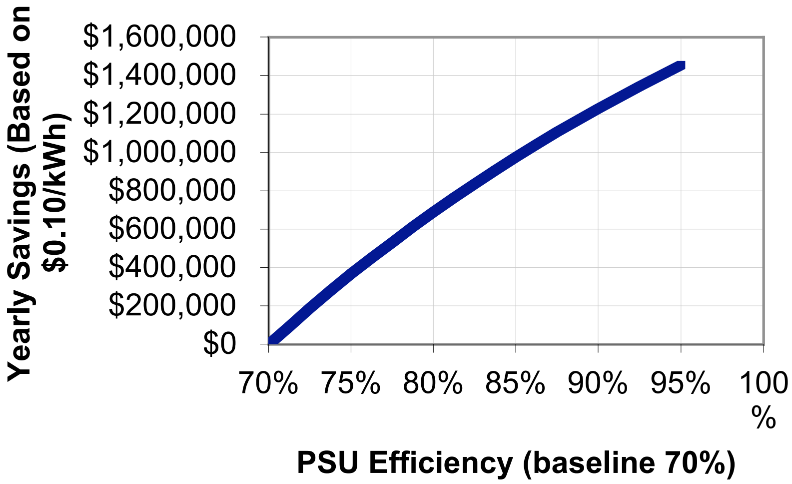

Figure 6. Savings potential in a typical data center. Energy-efficient server power supply units (PSUs). Source: Ecos Consulting

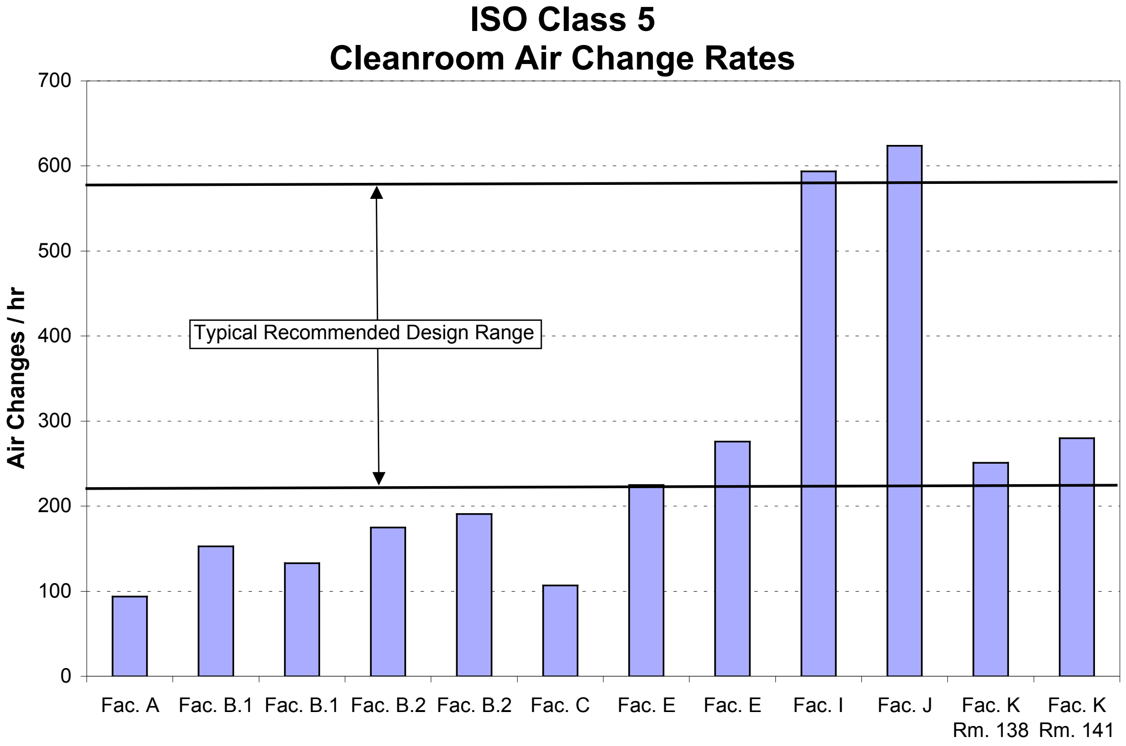

Figure 7. The chart tells us two important things: firstly, there is more than a factor-of-six variation in air-change rates for cleanrooms of an identical cleanroom "class" (cleanliness level), and, secondly, that many cleanrooms certified as sufficiently clean for their designated function, operate at well below the air change rates than called for by rules of thumb. Source: LBNL benchmarking database.

Figure 8. Prototype high-performance fume hood. Air is introduced in the frame ("face") of the hood, in front of the worker (see grill under right wrist), maintaining or improving containment and reducing energy use. Typical designs draw air from the general lab space around the worker, causing turbulence and higher-than-necessary fan energy use. Smoke in right panel shows air entering through the frame.

Figure 9. Cleanroom minienvironment.

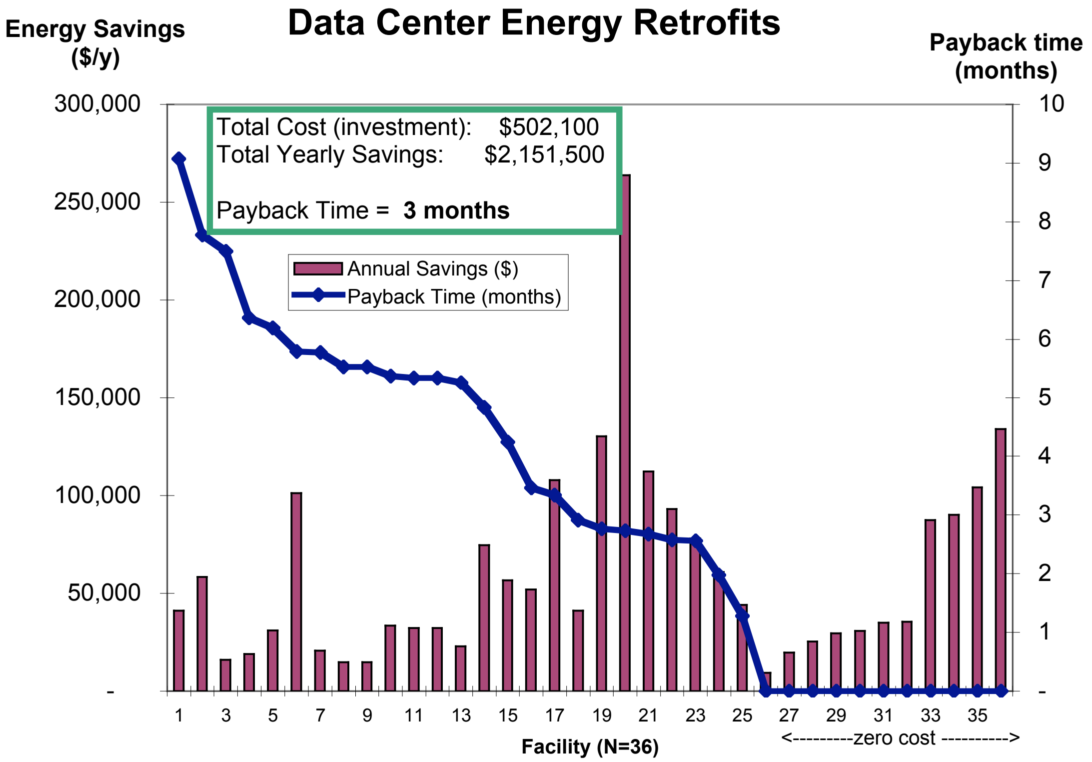

Figure 10. Energy savings for energy-efficiency upgrades at 36 data centers. Zero-cost items were labor-only, using in-house salaried staff.