From the Lab to the Marketplace: Government's Role in R&D and Market Transformation for Energy Efficiency in Buildings

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1. SYNOPSIS

Market transformation can be catalyzed by government-supported energy-efficiency R&D and energy planning analyses, as documented by U.S. case studies for lighting, windows, appliance standards, and building design tools.

2. ABSTRACT

Governments can use a variety of tools to create a fertile business environment for private-sector energy efficiency and catalyze market transformation. Government-supported research and development (R&D) has proven to be one very promising means of achieving these goals. This paper describes new analysis of selected federal R&D efforts in the United States over the past 20 years, including technologies, software, and analytical support of regulatory activities. The four cases presented (advanced lighting technology, spectrally selective window coatings, and appliance standards development, buildings energy design tools) are highly cost-effective, having resulted in $5.7 billion savings to US consumers as of 1993. In addition, these four program areas have helped create a $2.4 billion annual market for the products and services resulting directly from the research. By the year 2015, economic benefits of nearly $90 billion will likely have been achieved (net of up-front consumer costs), along with 200 million tons per year of avoided carbon-dioxide emissions. Other areas of government-supported research for which the benefits are not as directly quantifiable include climate change mitigation strategies, integrated resource planning for gas and electric utilities, enhancing indoor air quality, improving the efficiency of government's own facilities, and international assistance activities. In each case, close cooperation with industry has proven an essential factor in moving new technologies from the lab to the marketplace.

3. INTRODUCTION

One of the great challenges facing the U.S. Department of Energy is harnessing the power of its national laboratories in the post-cold-war era. With a workforce of over 30 000 scientists and engineers and a world-class R&D infrastructure, the labs are a major national asset. In addition to their mission to work on theoretical issues and basic sciences, DOE's national labs today make contributions towards addressing a variety of contemporary social problems, including understanding key health issues and developing new treatments, developing new uses for the global "information superhighway", understanding the causes of earthquakes, developing new materials and processes for manufacturing industries, and addressing a host of energy and environmental issues.

Most DOE buildings-related R&D is conducted by the Battelle Pacific Northwest Laboratory, Lawrence Berkeley Laboratory, the National Renewable Energy Laboratory, and Oak Ridge National Laboratory. Responding to Secretary of Energy Hazel O'Leary's Galvin Task Force on Alternative Futures for U.S. Department of Energy National Laboratories, the Lawrence Berkeley Laboratory's Center for Building Science has reviewed its history of doing research for the benefit of the U.S. and international economy and the environment via improved energy end-use efficiency.

The Center has operated as a catalyst in the energy-efficiency marketplace for two decades, providing an extraordinary rate of return on the federal research investment. From the outset, the approach was not one of belt-tightening, but rather a coordinated technological and deployment-oriented strategy for doing more with less energy while helping to reduce America's $500 billion energy bill (Figure 1) and protecting the environment.

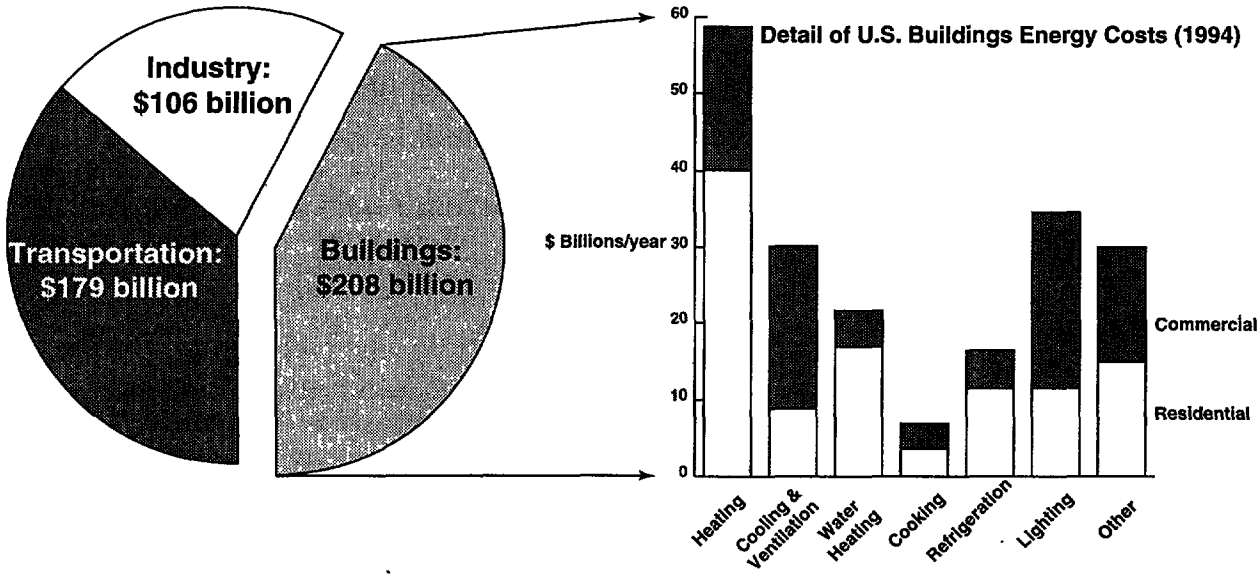


Figure 1. *Components of the $500-Billion U.S. Annual Energy Bill.*

Partnerships with industry, utilities, government agencies, universities, and other national laboratories are an integral part of the story.

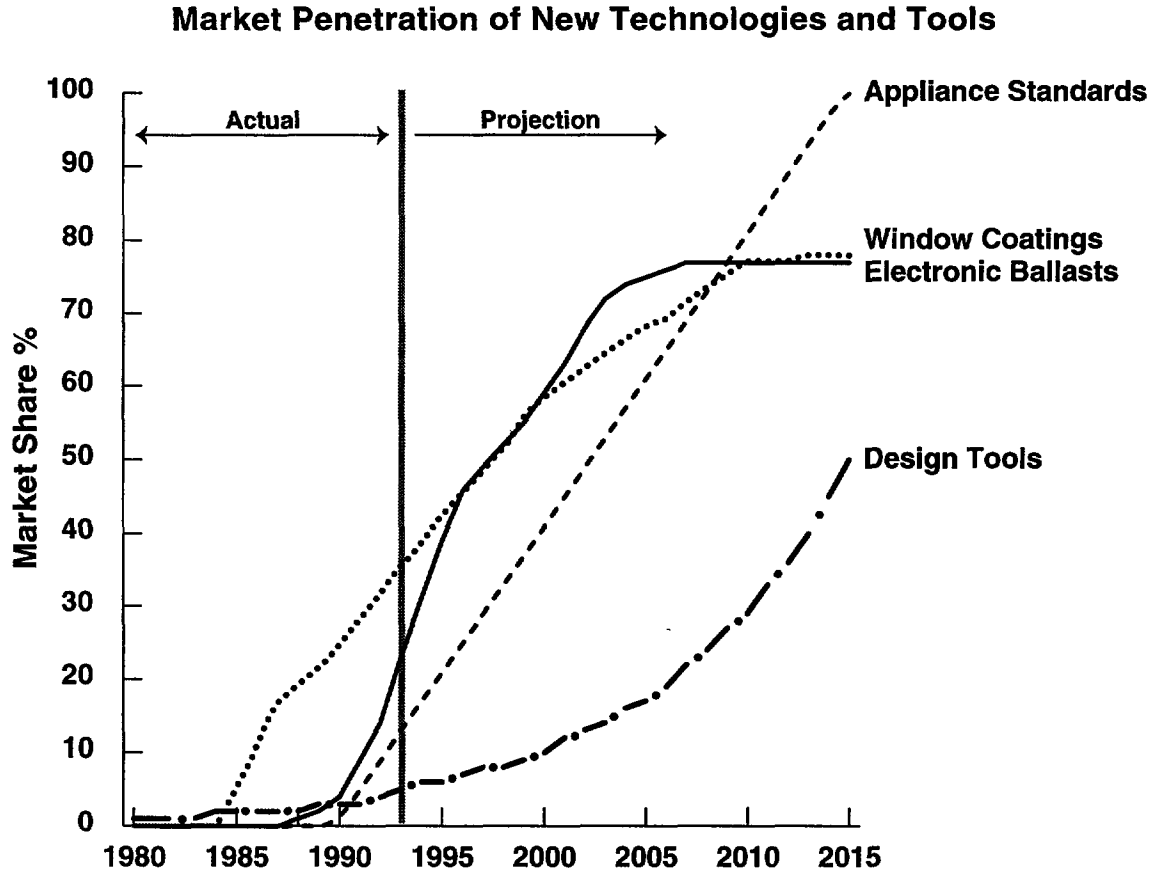
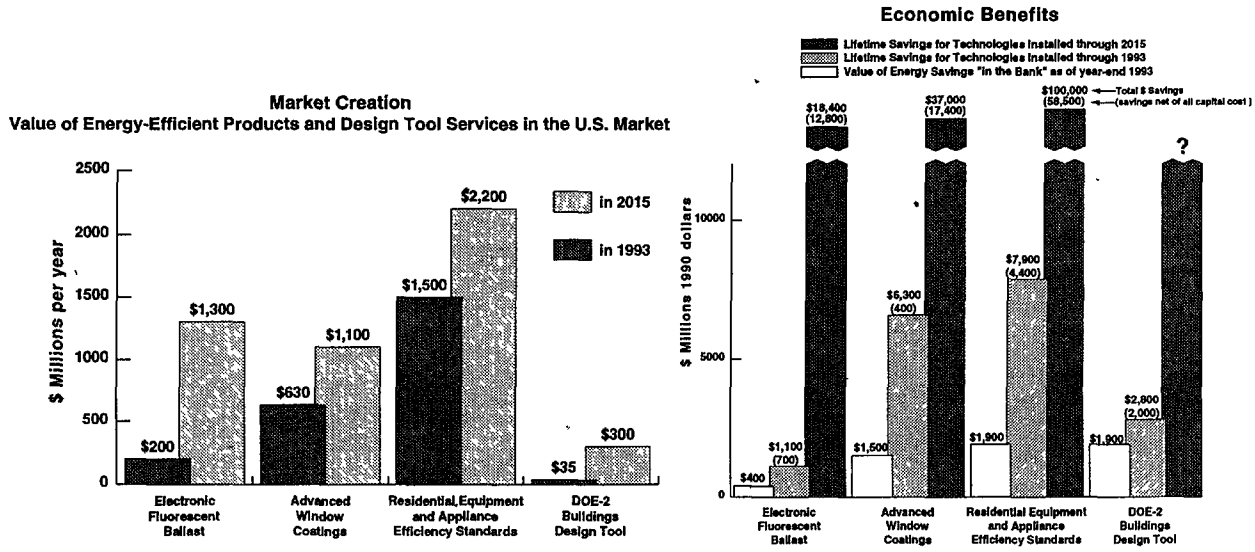


Figure 2. *Market shares for windows, ballasts, and design tools represent percentage application in new buildings; for appliance standards, the share represents the rate at which new appliances meeting the standard replace the existing stock.*

Since the mid-1970s, a cumulative $70-million U.S. Department of Energy research and development investment at LBL helped to spawn a $2.4-billion annual U.S. market for four technologies and services. Market penetration has increased rapidly in all four cases (Figure 2). As of 1993, this R&D investment leveraged energy savings worth an estimated $5.7 billion to consumers (with $1.3 billion in 1993 alone). By the year 2015, electronic ballasts, advanced glazing materials, and residential appliance standards will be saving consumers $16 billion annually (Figure 3).



These and other savings will be facilitated by new computer design tools, also developed at LBL. LBL's broader role in the buildings arena includes analyzing public policy issues, ranging from global climate change, to utility planning, improving indoor air quality in energy-efficient ways, helping government manage its own energy use, and contributing to various education and technology transfer goals.

It may be asked why the private sector does not on its own carry out such projects. In some cases this is indeed possible, but often federal involvement in energy efficiency can catalyze and accelerate market forces. Government efforts are motivated by the following factors:

- Market barriers (information, capital, price signals, etc.)
- Fragmentation of the buildings sector
- Opportunity for exercising leadership by example--making its own buildings into showcases
- Educational role--students, the public, commercial enterprises
- Independent evaluation of technologies / fuel neutrality
- Uniquely positioned for standard-setting
- A mandate to address externalities (pollution, security, competitiveness)

Moreover, if government R&D accelerates the introduction and penetration of new technologies, there are corresponding incremental energy savings during that period whose value can easily exceed the government investment.

4. SPECIFIC CASE STUDIES

4.1. Accelerating the Market for Energy-Efficient Lighting

The high-frequency electronic ballast is a technology that improves the efficiency of fluorescent lighting systems by up to 30% and enhances quality and flexibility. The electronic technology also allows for continuous dimming capability, which enables electricity savings through the use of daylighting. During the incubation of the electronic ballast industry in the late 1970s, LBL contracted with three small companies to produce early commercial models. The intent of this early effort was to accelerate the availability of electronic ballasts by demonstrating their energy efficiency and reliability in typical building environments. After delivery to LBL for testing to assure compliance with specifications, the ballasts were installed at a demonstration site in a utility office (PG&E) in San Francisco.

The results of these early demonstrations were widely publicized at technical and trade conferences. Later work at LBL helped improve the quality of the ballasts and validate the potential for energy savings from dimming. The current market share of electronic ballasts is 23% of all ballasts sold. More recent LBL efficient lighting breakthroughs are now entering the market, including super-efficient compact fluorescent fixtures (Figure 4).

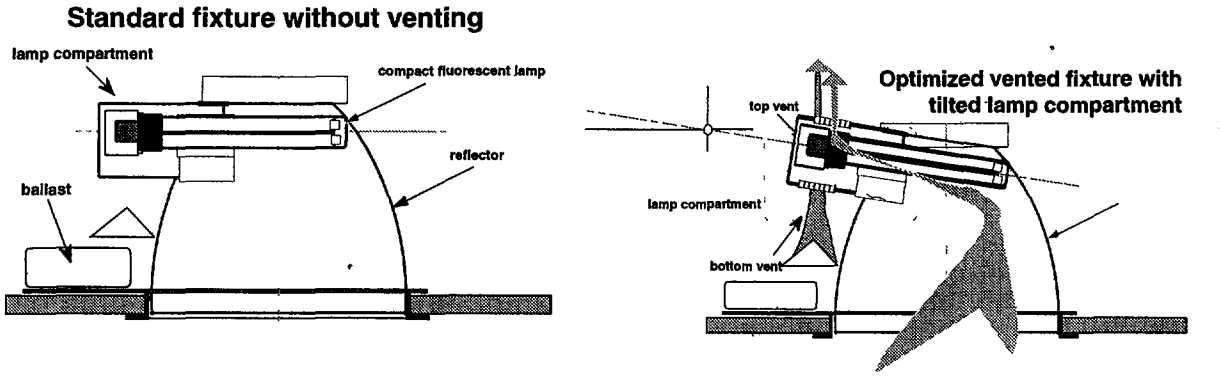


Figure 4. *Allowing for passive ventilation, and tilting lamp to keep excess mercury away from hot lamp electronics, increases fixture light output by about 20%.*

4.2. Seeing Windows Through

Although largely invisible to the human eye, windows with advanced coatings offer a one-third efficiency advantage over ordinary double-glazed windows by selectively blocking unwanted heat gain or loss. LBL's research began by developing a clear understanding of the heat transfer mechanisms in windows and identifying technical opportunities for reducing those gains and losses. Based on the findings, LBL became a pioneer in the commercialization of "low-emissivity" windows, awarding subcontracts to several firms to develop prototype coatings and new low-cost thin-film deposition processes. The performance of the coatings was tested at the Laboratory and new computer models were developed to determine the best use of the coatings in the overall window system. By the mid-1980s, virtually every major manufacturer was offering low-E windows. LBL developed design concepts using two low-E coatings and new gas fills that would cut energy losses by an additional 50% compared to conventional low-E glazing. The Lab then teamed with five manufacturers and suppliers (Andersen, Cardinal IG, Owens-Corning Fiberglas, Pella, and Southwall Technologies) and the Bonneville Power Administration in a program to convert the window concept into commercial prototypes. Within two years of this demonstration project, one of the participating manufacturers introduced the first commercial "superwindow" to the market, combining low-E coatings with energy-saving gas fills. The current market share of low-E glazings is 36% of all windows sold. The window industry's National Fenestration Rating Council (NFRC) recently adopted LBL's computer model (Window 4.1) as the definitive method of estimating window performance and creating energy labels for windows (Figure 5).

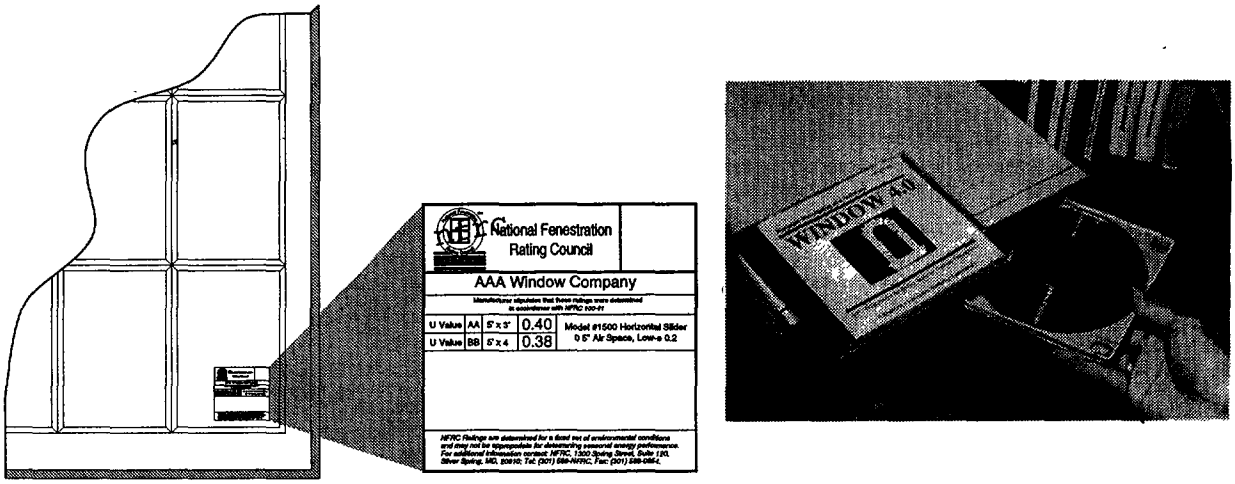


Figure 5. *The WINDOW 4.0 software and manual were published on a CD-ROM disc for initial distribution to 15,000 building industry professionals attending the A/E/C Systems Show. The Window software is the basis of NFRC labels.*

4.3. Setting the Standard for Energy Efficiency

Government R&D programs extend beyond the domain of specific technology development. As an illustration, LBL has become the national center for appliance standards analyses. Its program provides the technical, economic, utility, and manufacturer-impact analyses on which DOE bases mandatory standards that now apply to all major U.S. appliances and space-conditioning systems. In addition to technology-oriented research, the LBL program has provided pivotal support for understanding how the market functions and how certain market barriers to energy efficiency warrant the application of legislative measures such as standards and labeling. The current market share is virtually all applicable equipment sold. Figure 6 shows the impact of standards on the refrigerator marketplace.

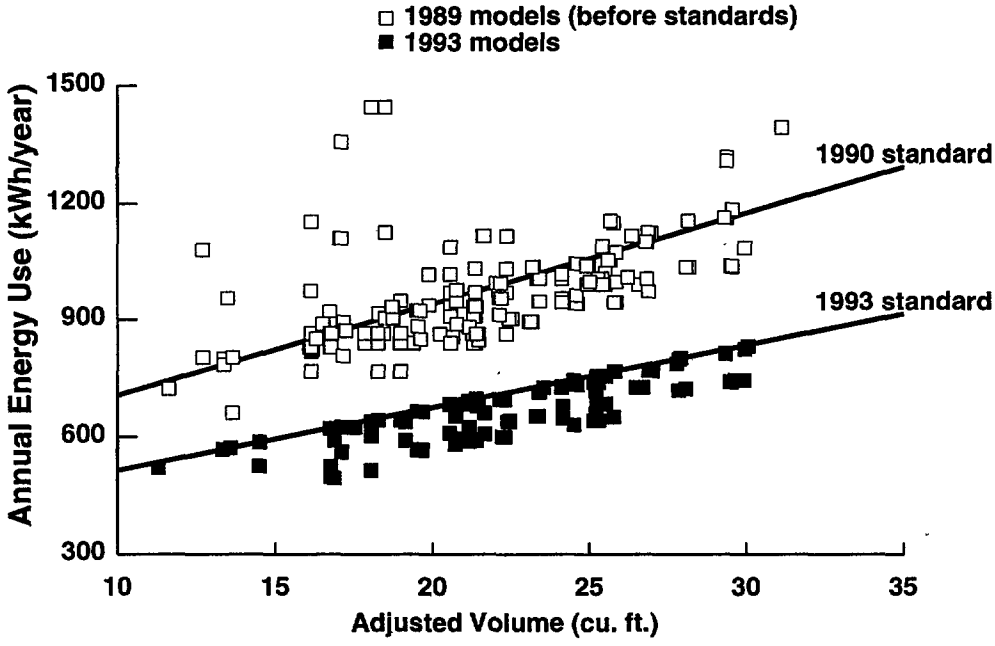


Figure 6. *The 1990 refrigerator standard eliminated many of the models sold on the market as of mid-1989. None of the pre-1990-standard models met the forthcoming 1993 standard. By 1993, some products beat the standard by as much as 15%. Each point represents a specific top-mounted refrigerator-freezer with an automatic defrost feature. Note that the standards are expressed as a linear relationship between a refrigerator's volume and its energy use, rather than as single energy-use values. ("Adjusted volume" is an adaptation of the nominal refrigerator volume, in which freezer volume is inflated by a factor of 1.63 to yield an equivalent refrigerated volume.)*

4.4. Tools for Building Designers

LBL's DOE-2 program is a powerful computer-based design tool for evaluating the energy implications of complex building design alternatives. Beginning in the mid-1970s, LBL worked with Los Alamos and Argonne national laboratories to develop the predecessor to DOE-2. The objective was an hourly whole-building energy analysis program that could simulate all building types in all climates, and that was unbiased, well-documented, and open to public scrutiny. A private company, Consultants Computation Bureau, assisted with interface development and programming. Continued improvements have been supported by DOE, various utilities, and the Electric Power Research Institute. A number of companies have converted DOE-2 into a PC-based program, or developed and marketed ancillary software. There are 1,000 user organizations today, in 42 countries. DOE-2 is used in the design of about 5% of all commercial buildings by floorspace, and users report that it enables them to routinely identify an extra 20% energy-savings opportunity.

The program has also been the basis of four major standards, the California Title 24, the Building Energy Performance Standard, and the DOE/ASHRAE 90.1 and 90.2 standards for commercial and residential buildings. As a measure of the impacts, the California Energy Commission estimates that the annual energy cost savings from the Title 24 standard was $420 million in 1985, $970 million in 1992, and will increase to $1.6 billion in 1999. The cumulative savings are estimated to be: $4.9 billion (1985-1992), and $13.8 billion (1985-1999).

5. ON THE HORIZON

Research and development activities are ongoing in the four areas just described. Future directions in the lighting area include helping industry develop more efficient light sources such as the sulfur lamp (Figure 7), "tuning" the light spectrum to optimize visibility and reduce energy use, and analyzing market transformation programs for technologies like residential light fixtures. LBL advanced coating technology will lead to "smart windows," whose dynamic coatings change their windows from clear to reflective. Other work in progress updates existing efficiency standards, expanding into non-residential end-use areas (e.g. thermal distribution, small motors, lighting ballasts, and HID lamps). The cooperative development of PowerDOE, a PC-based, user-friendly interface for DOE-2, and an expert system module called the Building Design Advisor (BDA), is continuing in a joint private/public team with support from the Electric Power Research Institute, utilities, the California Energy Commission, and the US DOE (Figure 8).

Figure 7. *LBL researcher examines prototype sulfur lamp, with an efficiency goal of 50% greater than fluorescent lighting systems.*

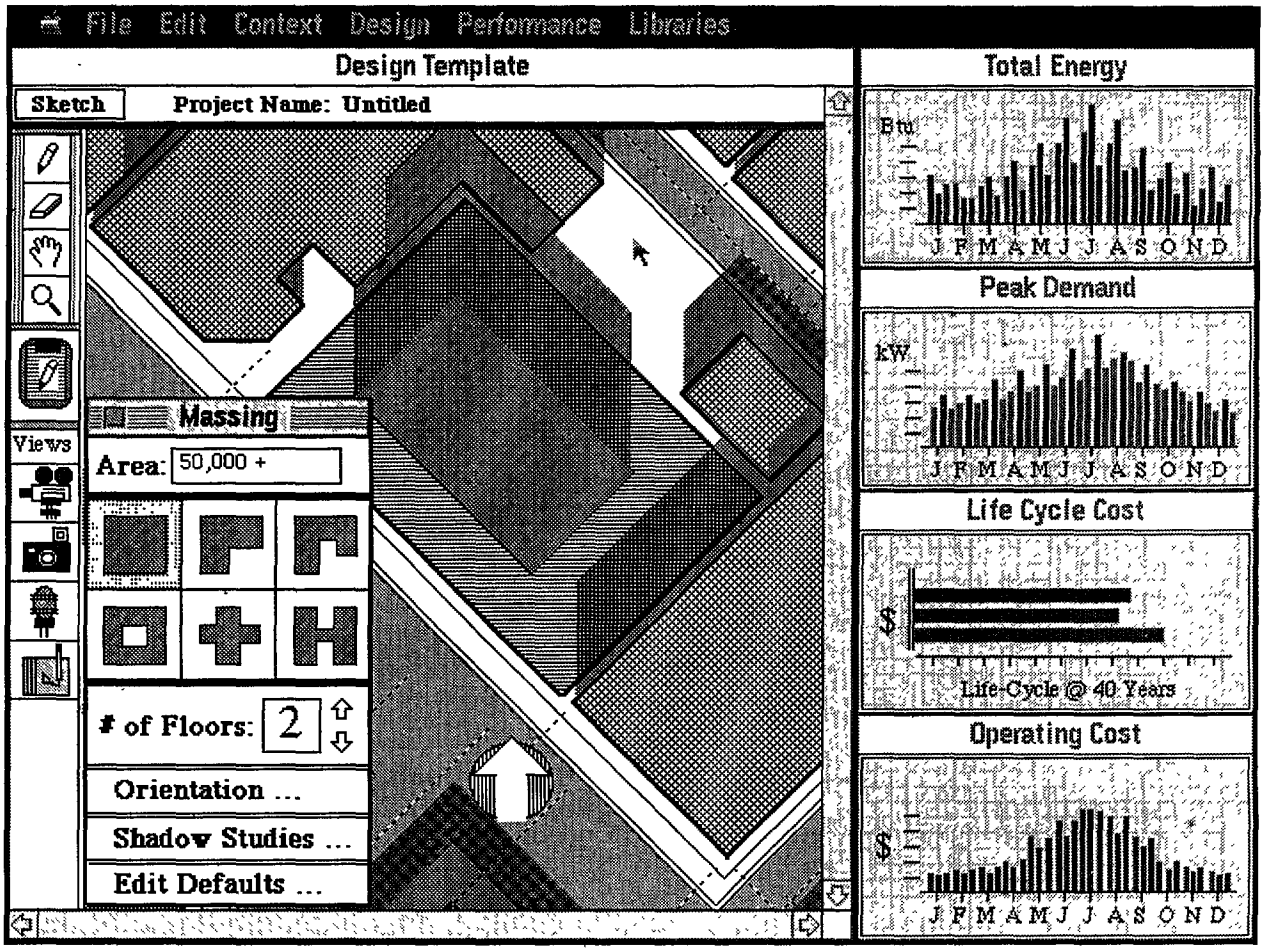


Figure 8. *Through a schematic design tool that incorporates shadow-casting visualization, the Building Design Advisor (BDA) will assist building designers with initial building massing and orientation decisions, providing feedback on multiple performance considerations, such as daylighting, solar gain, and shading from trees. The four charts compare key indicators for three design scenarios. DOE-2 will be the computational engine behind BDA.*

6. LBL'S BROADER ROLE IN THE BUILDINGS ENERGY ARENA

Although best known for its R&D and technology spin-offs to industry, the US DOE buildings energy research programs have also distinguished themselves in several other respects. As a U.S. Department of Energy laboratory, LBL contributes technical input to public policy issues such as global warming, works with utilities on new paradigms for energy planning, examines the effect of the indoor environment on health and comfort, helps the government manage its own facilities more efficiently, and addresses energy problems locally and internationally.

6.1. After the Cold War, in a Warming World

The end of the cold war, the Administration's new energy programs, and various initiatives by states and utilities have created new challenges and opportunities for the country's national laboratories. The United States produces one-quarter of the world's "greenhouse-gas" emissions. Laboratory programs that have helped to set the stage for achieving emissions reductions include participating in the National Academy of Sciences "Mitigation Panel" on climate change and contributing to the current Administration's Climate Change Action Plan (the "cool communities" action was developed at LBL). The Laboratory also assists DOE in developing and implementing its international energy-policy activities related to climate-change mitigation.

6.2. Partnering with Electric and Gas Utilities

For some years, LBL has worked closely with a number of utilities, their national trade associations (the Electric Power Research Institute and the Gas Research Institute), and especially, state regulatory utility commissions, and the

National Association of Regulatory Utility Commissioners. The Lab's energy-efficiency programs have aided in the development of new methodologies of energy demand forecasting, evaluation of the impacts of energy-efficient technologies on utilities, and market-based programs that utilities mount to deploy those technologies. LBL researchers pioneered the procedures for making "conservation potential" studies, now used routinely by many utilities around the nation. Other work has supported the trend towards utility regulatory reforms across the nation that redefines utility profit rules to decouple profitability from sales volumes. This approach is intended to motivate utilities to market programs that lead to energy savings.

The utilities team has authored definitive "primers" on integrated resource planning (IRP) for gas and electric utilities, which have been translated into several languages (Figure 9).

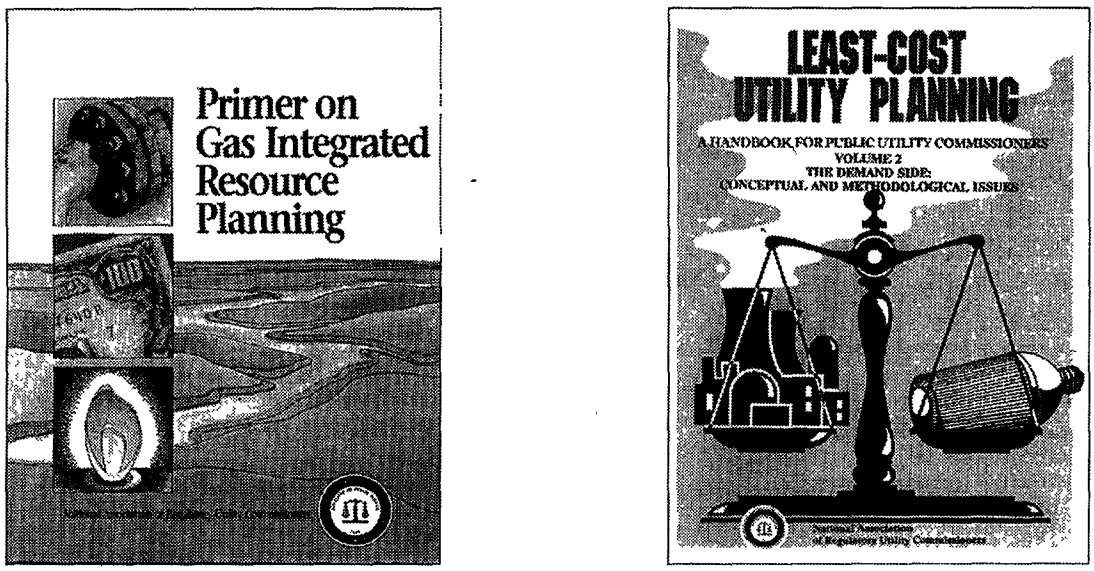


Figure 9. *LBL has authored two handbooks to help gas and electric utilities incorporate energy efficiency and other least-cost strategies into the traditional planning process. The handbooks were prepared at the request of the National Association of Regulatory Utility Officials (NARUC).*

Their other activities include operating the Advanced IRP Seminar for regulatory staff, and providing independent review of energy savings estimates of utilities, for example for the energy commissions of California, Wisconsin, and Michigan.

Beginning in the mid-1980s, LBL researchers began investigating electricity use and energy-saving opportunities for computers and office equipment. At about 30 TWh, equivalent to the power produced by 24 250-megawatt power plants, office equipment today represents the fastest-growing electricity load in commercial buildings. The savings potential is 25-50%, much of which is achievable at little or no cost by switching idle equipment to a "sleep" mode. LBL studies, in collaboration with electric utilities, the Electric Power Research Institute, international groups, and industry, provided the technical basis for EPA's successful "Energy Star" labeling program for office equipment.

6.3. Clearing the (Indoor) Air

Research on the indoor environment can help reduce the cost of health problems related to poor indoor air quality. An improved indoor office environment can increase worker productivity as well. If such measures help avoid even one or two absentee days per person, the savings can equal the total cost of all building energy used by that employee for an entire year.

People are indoors about 90% of the time, and indoor air pollutant concentrations often substantially exceed outdoor levels. This faces the U.S. with a staggering healthcare cost of about $1 billion annually. Although peoples' exposures to air pollutants are dominated by indoor exposures, almost all research and regulatory attention is placed on outdoor air quality. Indoor air pollutants are responsible for premature deaths in 10 000 lung cancers annually (caused by radon), 1 500 deaths due to accidental carbon monoxide poisoning, and 10 000 related medical visits. Exposure of young children to environmental tobacco smoke causes an estimated 150 000 to 300 000 lower respiratory tract infections annually, such as bronchitis and pneumonia. Asthma--with its $6.2 billion annual U.S.

healthcare cost--is another malady exacerbated by poor indoor air quality. The indoor environment also affects the rates of transmission of important infectious diseases, such as influenza, tuberculosis, and common colds. More than 20 million cases of influenza occur annually in the U.S.

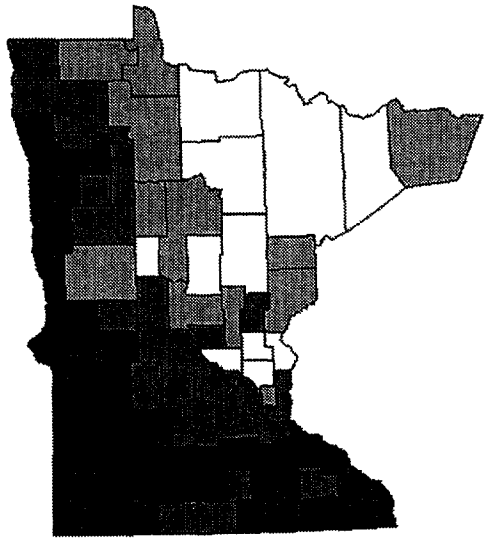


Figure 10. *Estimated geometric mean indoor radon concentration by county for Minnesota. Darker shades indicate higher indoor radon levels. Homes in light counties have estimated concentrations below 2.5 pCi/L (picocuries per liter); darkest counties are greater than 5.5 pCi/L. For comparison, the U.S. Environmental Protection Agency recommends remedial action when annual average levels in the living area reach or exceed 4 pCi/L.*

Some energy-saving measures can create indoor air quality problems unless properly conceived and implemented. Mitigating these problems can waste energy, for example, excess ventilation without heat recovery. Recognizing that both energy efficiency and the quality of the indoor environment need optimization, LBL established the Indoor Environment Program in the 1970s. The program houses one of the world's premier research groups on the environmental effects of indoor radon. Its research has uncovered basic insights into how radon gas from the soil gets into homes. After cigarettes, radon is the second largest cause of lung cancer. LBL researchers are using geographic information systems to pinpoint parts of the country with the highest radon levels. These results are helping to craft national policy recommendations for a remediation strategy that is more effective and less costly to the taxpayers than the "shotgun" approach of trying to measure and take action on every home.

The well-known but poorly understood "sick building syndrome," which may affect as much as 20% of all new office buildings, has also been the object of study at the Laboratory. Among the conclusions of this work: occupants suffer a greater number of building-related health symptoms in structures with air-conditioning compared to those with natural ventilation.

In addition to illuminating the basic processes influencing indoor air quality, LBL's program has helped stimulate and accelerate technologies and strategies for measuring and controlling indoor air pollution in energy-efficient ways. These technologies include low-emission building materials and appliances, heat-recovery ventilation systems, blower-door technology (for testing air leakage in buildings) and energy-efficient radon control technologies. An innovative "airvest" system promises to reduce spraybooth worker exposure to pollutants by many fold, while cutting ventilation energy costs in half. Researchers have also developed passive samplers for indoor air quality (for example, the formaldehyde-based air samplers now sold by Air Quality Research in North Carolina).

Research at LBL has made substantial contributions to twelve nationally used ASHRAE and ASTM standards pertaining to ventilation and air quality for the built environment.

6.4. Government Partnerships

Buildings research at LBL has helped several Administrations improve efficiency in federal buildings as a means of saving taxpayer dollars and of providing national leadership by example. During the 1980s, researchers helped the Department of Housing and Urban Development track energy use and identify ways of reducing the $1 billion/year

energy bill in public housing. Their research also led to new legislation removing barriers to energy efficiency in public housing and establishing new business opportunities for private energy service companies. The Laboratory's most recent effort was its participation in an elite team to carry out the "Greening of the White House" project, unveiled by President Clinton on Earth Day 1994. Researchers have provided technical support to DOE's own In-House Energy Management program, which has already achieved annual savings of approximately $155 million in DOE energy bills. The Laboratory has also supported the Federal Energy Management Program (FEMP) for many years, and will begin playing a key role in carrying out a high-profile energy management project at the San Francisco Presidio (a former military base, transferred to the National Park Service in 1994) on behalf of FEMP. LBL researchers are also working with the Federal Aviation Administration to identify ways in which advanced energy-efficient technologies and modeling tools can make the nation's air traffic control towers and facilities into better work environments with improved comfort, visibility, and equipment reliability, thereby improving air travel safety.

6.5. Providing a Helping Hand to States

For two decades, LBL has cooperated in various ways with individual states. For example, the Washington State Energy Office asked LBL to provide technical assistance on their residential construction projects and proposals for creating a new energy efficiency code. LBL also conducted projects with the New York State Energy Office and the New York State Energy Research and Development Administration involving ventilation and infiltration in low-income multifamily buildings. Over the past few years, LBL has provided technical evaluation for the "Energy Edge" project, in which the Bonneville Power Administration funded the Washington State Energy Office and the Oregon Department of Energy to build and evaluate state-of-the-art commercial buildings throughout the Pacific Northwest region.

LBL researchers have provided technical support to the California Energy Commission since its inception, including assisting the state's energy-demand forecasting process, providing tools for developing building standards, evaluating spending plans for PVEA (oil overcharge) funds, and developing methods for implementing home energy rating systems. The Laboratory has collaborated on a broad range of topics with each of California's major electric and gas utilities (Los Angeles Department of Water and Power, Pacific Gas and Electric, Sacramento Municipal Utility District, San Diego Gas and Electric, and Southern California Edison).

Marking an important watershed in utility regulation, the Laboratory played a technical assistance role in the so-called "California Collaborative," in which all the state's utilities (and their regulators) agreed to reform utility profit rules to provide new economic incentives for utilities to pursue energy efficiency. More recently, LBL has been part of the steering team of Pacific Gas and Electric's $20-million Advanced Customer Technology Test (ACT2). This project is the nation's largest high-profile demonstration of the technical and economic potential of energy-efficient technologies and practices in commercial and residential buildings.

LBL is also the home of the California Institute for Energy Efficiency (CIEE), an innovative partnership between California's energy utilities, the California Energy Commission, the California Public Utility Commission, the University of California, and DOE. CIEE funds and coordinates $3 million per year of research at California universities and University-affiliated DOE laboratories, focusing on technologies crucial to the state and regional context. The Institute emphasizes applications which simultaneously improve end-use efficiency and lower utility operating costs.

6.6. International Activities

Many of the DOE efficiency-related activities have spun off ideas and information to other countries with beneficial effects. A number of countries have emulated LBL methodologies for developing appliance and building standards. Low-e windows and electronic ballasts are also finding overseas markets. The DOE-2 program is used in 42 other countries and has been used to develop building energy efficiency standards for many countries, including the ASEAN nations (Singapore, Thailand, Malaysia, Indonesia, and Philippines), Canada, Brazil, Kuwait, Saudi Arabia, Hong Kong, Australia, and Switzerland.

LBL's own activities in the international arena include energy demand and policy analysis for industrialized and developing countries, and formerly planned economies. Two illustrative projects focus on Russia and China. Components of these projects include helping Russian window companies identify efficiency-enhancing technologies within their defense industry, establishing an Energy Efficiency Center in Beijing, and assisting in the formation of joint ventures between U.S. and Chinese industries. DOE Laboratories have provided general training and technology transfer for dozens of utilities and energy planners from outside the United States.

LBL's international group is helping scientists and energy policy makers from 16 countries in Eastern Europe and the former Soviet Union, Asia, Africa, and Latin America assess their opportunities for reducing emissions of greenhouse gases from the energy sector. With this goal, the Laboratory has established networks of experts in energy and forestry for the U.S. Environmental Protection Agency, the federal entity responsible for creating developing country emissions scenarios used by the prestigious Intergovernmental Panel on Climate Change. LBL is participating in the U.S. Country Studies Program through the U.S. Department of Energy. The Country Studies initiative grew out of the commitment made by the United States at the 1992 Earth Summit held in Rio de Janeiro to help countries comply with the Framework Convention on Climate Change.

In parallel with these specific programs, an informal program has been established through which energy researchers from developing countries work at LBL on projects of mutual interest. During the past ten years, more than 100 researchers have spent upwards of 50 person-years at the Laboratory on such projects.

6.7. Education and Technology Transfer

To foster the adoption and use of energy-efficient technologies in buildings, the Laboratory relies on its information and technology transfer program. The program ensures that research results are transferred quickly to utilities, major builders and real estate developers by emphasizing strong working relationships with key professional, trade association, and research organizations. These groups serve as intermediaries and brokers in reaching manufacturers, consumers, and the fragmented building-sector industries. Additionally, LBL publishes research results on the Internet's "information superhighway."

Education is also central to LBL's strategy for promoting energy efficiency. To this end, the Laboratory has a relationship to a major university (the University of California at Berkeley) that is unique among the national labs. Dozens of faculty, staff, and students from a variety of disciplines work in LBL's energy-efficiency programs. Some graduates stay on at LBL while others move into industry or the public sector.

7. CONCLUSIONS

Government supported R&D on energy efficiency can benefit energy users and the companies that provide the technologies or services required to achieve energy savings. In the case of the United States, such investments have yielded savings worth many times their cost. Each country has its own needs and philosophy about government's role in this area. However, given the finite economic resources available for such R&D, it is important that program managers select projects that would not be pursued single-handedly by industry, or which would come to market and begin saving energy significantly faster with government support.

8. ACKNOWLEDGMENTS

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