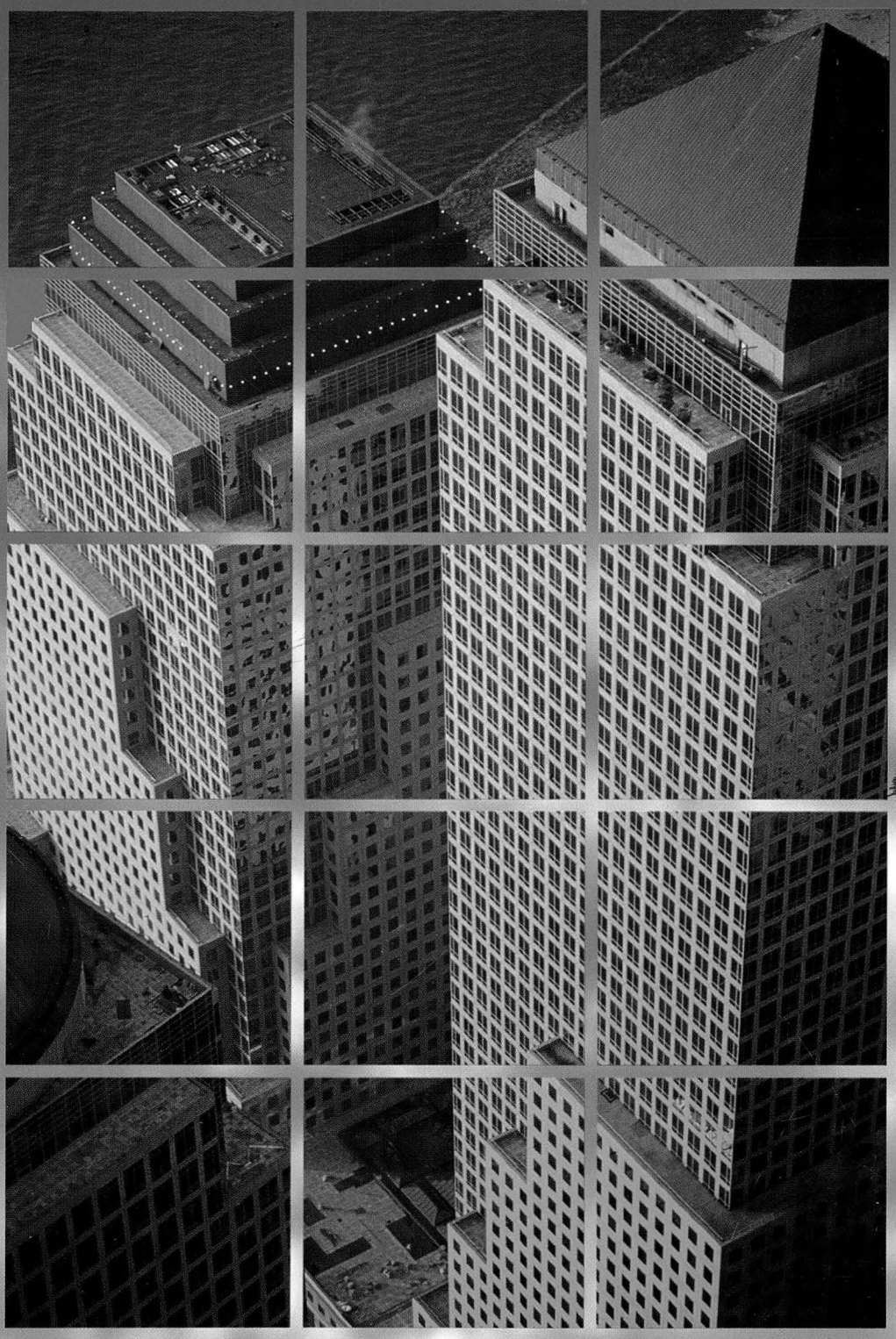


From the Lab to the Marketplace

Making America's Buildings More Energy Efficient

Lawrence Berkeley Laboratory

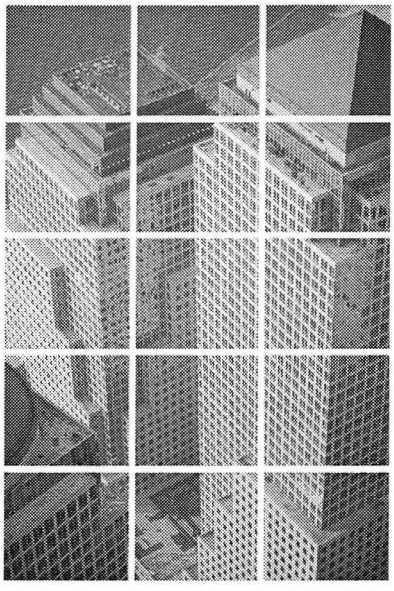
PUB-758
Copy 1
REFERENCE COPY
Does Not
Circulate
Bldg. 50 Library.

For further information about the programs described in this report, contact Dr. Evan Mills:

510/486-6784
Email: emills@lbl.gov
World Wide Web: http://eande.lbl.gov/Building_Science.html

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.



From the Lab to the Marketplace

Making America's Buildings More Energy Efficient

Prepared by
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

January 1995

SUMMARY

Since the mid 1970s, DOE has invested some $70 million in research and development at Lawrence Berkeley Laboratory (LBL) for energy-efficiency studies of advanced building technologies. That investment has helped spawn a $2.4-billion U.S. market for key products—energy-efficient lighting and advanced window coatings—and efficiency standards for residential equipment and computerized tools for more efficient building design. By 1993 DOE's initial investment had reduced consumers' energy bills by an estimated $5 billion ($1.3 billion in 1993 alone). By 2015 we estimate that the products of that investment will save consumers $16 billion annually.

But LBL research partnerships address a host of other building technology issues as well—building technology issues whose economic benefits are less easy to quantify but whose overall worth is equally important. We analyze public policy issues such as the role of efficiency options as a mitigation strategy for global climate change. We develop planning and demand-management methodologies for electric and gas utilities. We identify technologies and analytical methods for improving human comfort and the quality of indoor air. We contribute to the information superhighway. We focus on the special problems and opportunities presented by energy use in the public sector. And we do all these things at the local, national, and international levels.

At LBL, we are part of the multi-laboratory, interdisciplinary approach to building technology research supported by DOE's Office of Energy Efficiency and Renewable Energy. We also participate in buildings-related research supported by DOE's Office of Health and Environmental Research, other federal agencies, and industry. This document describes LBL's role within this wider effort.

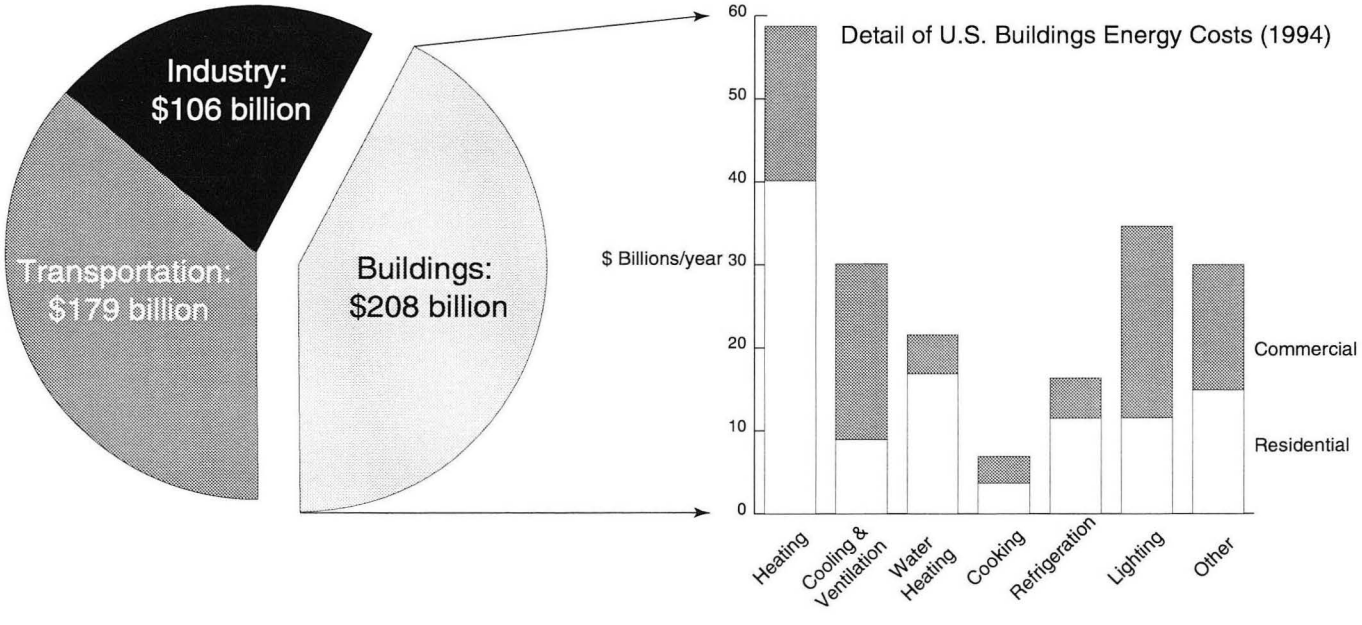
BRINGING NEW TECHNOLOGIES TO MARKET

As part of the DOE national laboratory system, Lawrence Berkeley Laboratory has acted 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, our approach was not one of belt-tightening, but rather a coordinated technological and deployment-oriented strategy for doing more with less energy and, at the same time, saving money. Partnerships with industry, utilities, government agencies, universities, and others are an integral part of that strategy. LBL's accomplishments in the building sector provide an example of how the national laboratories can serve the nation today and into the next century.

With a $500 billion per year national energy bill and more than half of our oil supplied by foreign sources, U.S. energy use has become a matter of strategic importance. There is little disagreement that wise management of our energy consumption is a national priority, and we are making substantial progress toward that goal. Thanks in part to new technologies and policies focusing on the efficient use of energy, leveraged by research and development (R&D) at the DOE national labs, the national energy bill is about $100 billion lower today than it would otherwise have been.

Programs addressing energy and the environment promise relief for some of the most pressing issues of our time: the rising national energy bill, industrial competitiveness, international security, urban and indoor air pollution,

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

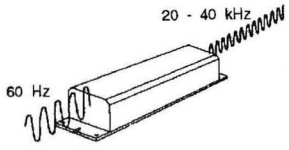


and the specter of global climate change. At the same time, it is recognized that energy-saving objectives must be coupled with goals of enhanced comfort, quality, productivity, and safety in the built environment.

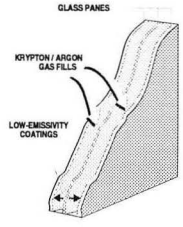
LBL's interdisciplinary research programs are positioned to guide new technologies from the lab to the marketplace. Research and development plays an important leveraging role in the marketplace by accelerating the commercialization and consumer acceptance of new technologies, while ensuring the quality of the indoor environment. This work is rooted in collaborations with equipment manufacturers, building professionals, utilities, and other national laboratories active in the energy sector. New technologies nurtured at LBL with multimillion-dollar research programs are yielding multi*billion*-dollar savings nationally as they successfully capture market share.

Four Highlights

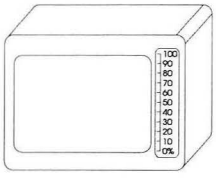
In the following pages, we present four case studies along with a discussion of future directions in each area:



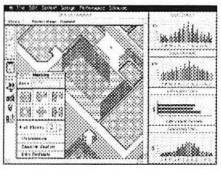
- **The electronic ballast**, a technology that improves the efficiency of fluorescent lighting systems by up to 30% and enhances their quality and flexibility. The current market share of electronic ballasts is 23% of all ballasts sold. Other LBL efficient lighting breakthroughs are also entering the marketplace.



- **Advanced energy-efficient window coating—**largely invisible to the human eye—that offer a one-third efficiency advantage over ordinary double-glazed windows by selectively blocking unwanted heat gain or loss. The current market share is 36% of all windows sold.



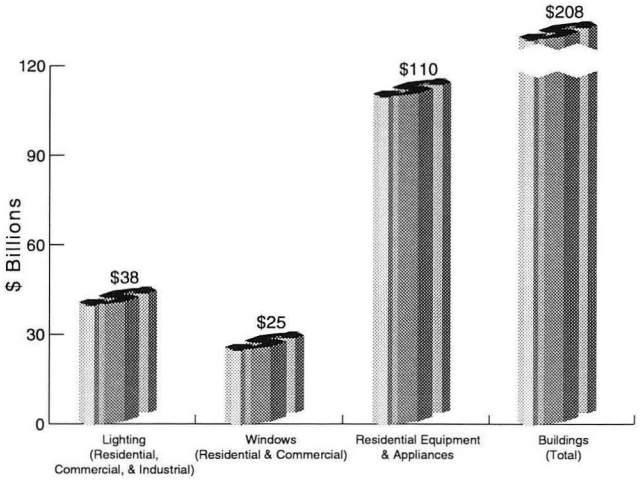
- **Residential equipment and appliance standards development,** in which LBL provides the technical and economic analyses used by the government to set mandatory efficiency levels for major household appliances and heating and cooling equipment. The current market share is virtually all appliances, air-conditioners, and furnaces sold.



- **DOE-2, a powerful computer-based design tool for reducing energy use in buildings**. Thanks to this computer software, building designers can now evaluate the energy implications of complex design alternatives. DOE-2 is currently used in the design of about 5% of all commercial buildings by floor-space. Users report that DOE-2 enables them to routinely identify an extra 20% energy-savings opportunity.

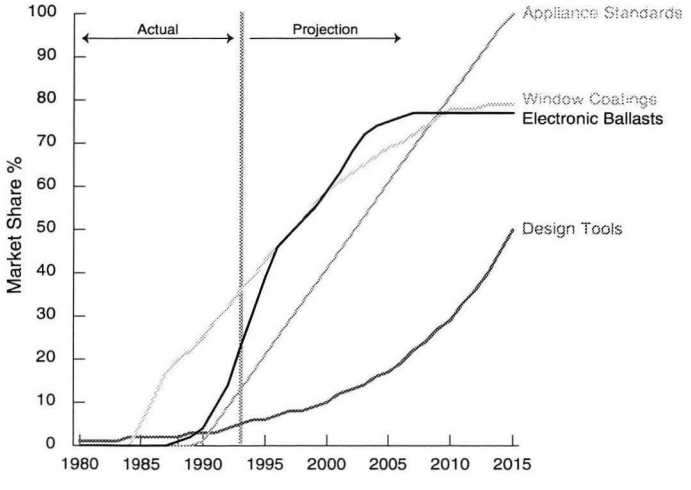
Each of the preceding four examples documents a different path to energy savings—with, in each case, a different role for LBL in developing these savings. The benefits are real and have been documented here using the best available information. This report assembles the best available data and provides the framework for understanding how DOE's investment ultimately serves the U.S. consumer.

Annual U.S. Buildings Energy Costs Targeted by LBL Research



Note: "Buildings" includes windows, equipment, lighting, and all other end uses.

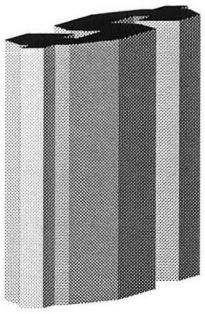
Market Penetration of New Technologies and Tools



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

ACCELERATING THE MARKET FOR EFFICIENT LIGHTING

$38 Billion

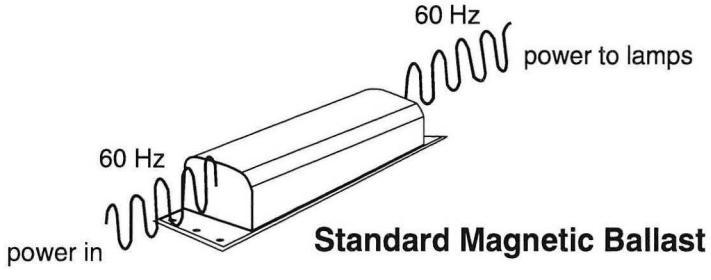


Lighting costs U.S. businesses and consumers nearly $40 billion each year. The strategic use of research dollars can trim billions from this annual bill. LBL's early work on the electronic ballast illustrates the potential payoff from lighting research and working with industry. Virtually unknown in the mid 1970s when the $3-million LBL research effort began, the electronic ballast today has captured a nearly 25% market share, with annual U.S. sales of about 24 million units ($200 million retail value). It has already saved $400 million in consumer energy bills. Net savings will grow to $13 billion by the year 2015. In current research efforts, LBL has transferred new light fixture design strategies to all major U.S. manufacturers and is fostering the development and commercialization of the world's most efficient white light sources. Other work on the effect of various types of light sources on humans may revolutionize the way efficiency and lighting are measured and thereby improve productivity in the workplace.

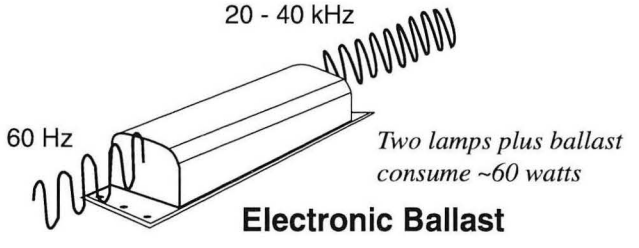
The Electronic Ballast—An Early Success

Fluorescent lights require ballasts, which help start and then control the current flowing through the lamp. An annoying flicker, hum, and energy loss are infamous hallmarks of the magnetic ballast, the industry standard for decades. More than a decade ago, LBL played a catalytic role in developing the high-frequency electronic ballast and in encouraging its market growth. Electronic ballasts not only eliminate flicker and hum, they also save energy by reducing electrical losses in both the ballast and the lamps. Electronic ballasts can also be designed for dimming, and can be made smaller and lighter than standard ballasts.

When our research on the electronic ballast was just beginning in the late 1970s, LBL contracted with three small companies to produce commercial models of high-frequency electronic ballasts for conventional fluorescent lamps. (At that time, no electronic ballasts were commercially available—even though the high-frequency operation of fluorescent lamps was known to improve energy efficiency.) The intent of this early effort was to accelerate the availability of electronic ballasts by demonstrating the energy efficiency and reliability of these new, energy-saving products in typical building environments. After the ballasts were tested by LBL to assure compliance with specifications, they 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 and showed that electronic ballasts could operate satisfactorily in a typical building environment and reduce lighting energy use by up to 30%.



Two lamps plus ballast consume ~90 watts



Two lamps plus ballast consume ~60 watts

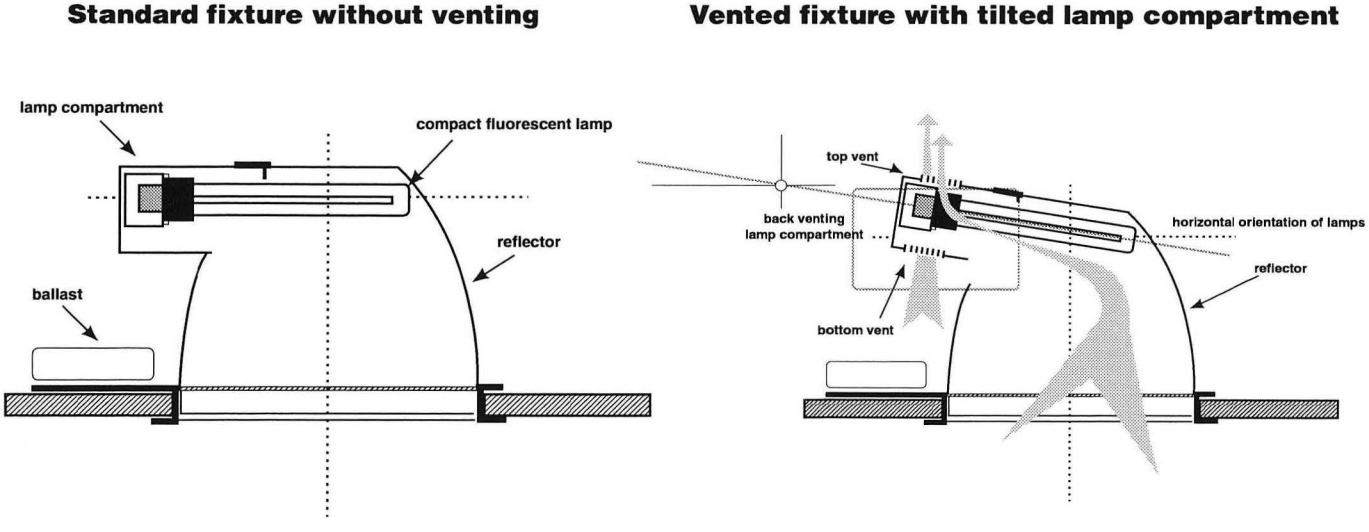
As a result of research efforts and continued quality improvements, the electronic ballast has developed from a laboratory curiosity to a proven and successful energy-efficient lighting technology. By 1993 electronic ballasts represented 23% of total ballast sales, and the electronic ballast is now an accepted mainstream product. They will likely replace magnetic ballasts in more than 75% of applications by 2015 as a consequence of utility and other incentive programs, and federal programs and standards.

The federal investment in electronic ballast R&D is about $3 million, leveraging a cumulative energy savings attributable to electronic ballasts from 1988 to 1993 of $400 million. Based on energy savings "in the pipeline," i.e., for technologies installed as of 1993, businesses and consumers will ultimately save $700 million (*net* of their extra capital investment), which will grow to $13 billion for technologies installed through the year 2015. In 2015, environmental emissions of approximately 73 million tons of CO_2, 157,000 tons of SO_2, and 144,000 tons of NO_x will be avoided through the use of electronic ballasts.

Beyond Ballasts

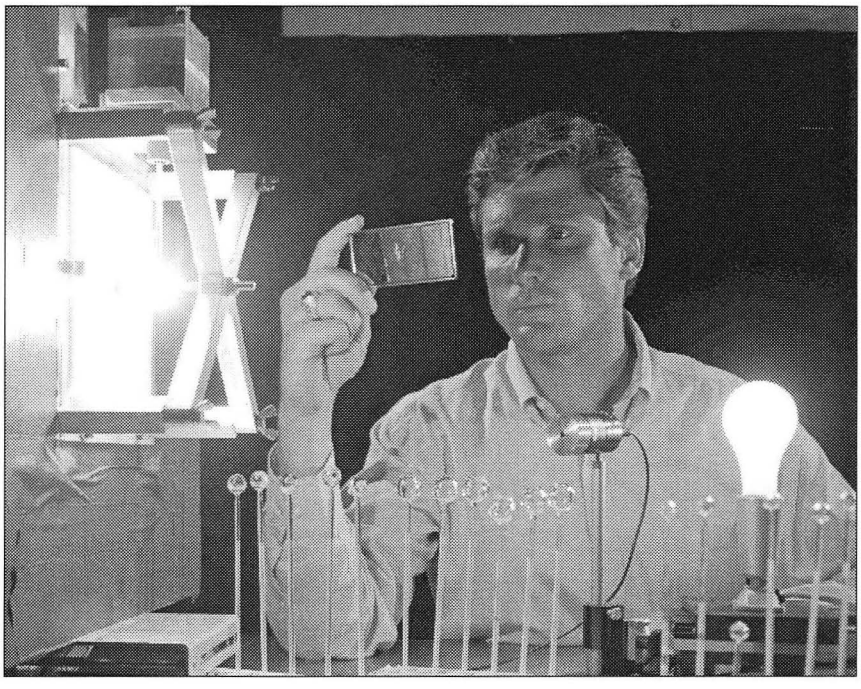
Current research focuses on LBL-industry collaborations to improve other lighting systems through advanced lamps, luminaires, controls, and daylighting strategies. One major area of emphasis is the search for near-term improvements to the traditional incandescent lamp. Although incandescent lamps are the most inefficient light source currently available, nearly two billion such lamps are manufactured annually in the U.S. LBL is working to optimize the performance of one alternative—compact fluorescent lamps (CFLs), which are four times as efficient as today's incandescent light sources. Lamp manufacturers have shown keen interest in the LBL design concepts. Osram, one of the world's largest lighting manufacturers, included the LBL work in its widely used *Compact Fluorescent Handbook.*

In 1989, lighting researchers began work with major manufacturers of compact fluorescent lamp fixtures. Early on, LBL researchers specifically targeted the recessed "can" fixture industry, which has annual sales of about 20 million units in the U.S. and has the fastest sales growth of any type of fixture. LBL pioneered a series of optimized low-cost fixture improvements that use conductive cooling or convective venting designs to eliminate excess heat buildup, thereby allowing up to 25% greater light output. Manufacturers such as Cooper Lighting, Delray, Edison Price, Indy Lighting, Kurt Versen, Lightolier, Lithonia, Microflect, Mitor, Prescolite, Reggiani, Staff, and Zumtobel have already incorporated LBL's efficiency-enhancing strategies into their product lines. Manufacturers see these improvements as enhancing their position in markets where many consumers are dissatisfied with the amount of light produced by conventional compact fluorescent fixtures. From the standpoint of national energy use, these improvements widen the market niche for CFLs and appreciably increase potential savings.



Allowing for passive ventilation and tilting lamp to keep excess mercury away from hot lamp electronics increase fixture light output by about 20%.

In another effort, LBL researchers are working with Fusion Lighting to create a novel light source that is 50% more efficient (~130 lumens/watt) than the best-available fluorescent systems and yet provides a far superior spectrum, similar to that of true sunlight. The so-called "sulfur lamp" contains no environmentally troublesome mercury, offers an extremely long service life, and has "tunable" color properties. It is dimmable and delivers efficiency unmatched by any currently available white light source.



LBL researcher examines prototype sulfur lamp.

LBL expertise in coupling radio-frequency power to electrodeless lamps has enabled Fusion Lighting to downsize a pre-existing product that was unlikely to ever reach the commercial marketplace. The large original lamp produces as much light as 175 full-sized fluorescent lamps and requires a microwave power supply and its own miniature air conditioner. Two new versions are downsized to the size of a coin and require no active cooling. One generates as much light as fifty fluorescent tubes, the other as much as two tubes. However, several technical and economic challenges must be overcome before the sulfur lamp will be commercially viable. Such intense light sources require a fundamental rethinking of the light fixture, which has spurred a program of R&D on "light guides"—long reflective tubes that can conduct and distribute this bright light over a large indoor area. Integrating these guides with architectural daylighting offers the prospect of buildings lit by daylight deep in their interiors. LBL helped demonstrate sulfur lamp and light guide systems at DOE's headquarters and at the Air and Space Museum, both in Washington, DC.

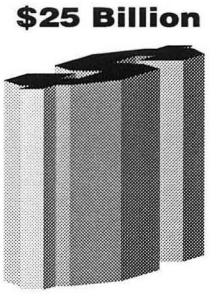
The Future

Complementing LBL efforts in technology development are research activities investigating lighting design and applications, and the human response to lighting. Interdisciplinary research performed in collaboration with medical experts has demonstrated that the fundamental measure of light—the "lumen"—is a poor measure of how people actually perceive light. This research suggests that by "tuning" the spectrum of light sources to optimize the responses of rods and cones in the eye, we will be able to see better and with less energy needed for illumination.

"Market transformation" is another development frontier. LBL researchers are providing technical support to groups that design innovative deployment strategies for efficient lighting. LBL has assisted DOE in developing national standards aimed at improving lighting efficiency and is supporting DOE and U.S. Environmental Protection Agency (EPA) efforts in designing a broad strategy to improve the market penetration of efficient residential lighting technologies.

LBL researcher adjusts a centralized light guide system consisting of a 250-watt metal halide lamp, a high-efficiency beam splitter, and four hollow light guides. This results in a lighting load of only 60 watts per work station with light levels even higher than those provided by typical fluorescent systems–and superior light quality. Eventually, sulfur lamps will be used with this system.

SEEING WINDOWS THROUGH



Energy lost through residential and commercial windows costs U.S. consumers about $25 billion a year, a loss comparable to the value of the oil delivered by the Alaska pipeline. LBL pioneered the commercialization of "low-emissivity" windows and labeling systems, which reduce the energy lost through normal, double-glazed windows by 35%. Thanks to LBL's close collaboration with window manufacturers, and a DOE investment of $3 million, the market share for these advanced windows has reached about 35% (with an annual market value of $630 million). Cumulative U.S. energy savings to date from these windows is $760 million and will reach $17 billion—net of added up-front costs—by 2015.

In 1976, in response to the energy crisis, DOE began a program at LBL to examine the potential of new, more efficient window technologies. In 1993, after almost 20 years of an R&D partnership with industry, that effort has resulted in sizable energy savings to U.S. building operators, and the development of a new line of energy-efficient window products that are generating sales and profit opportunities for window manufacturers.

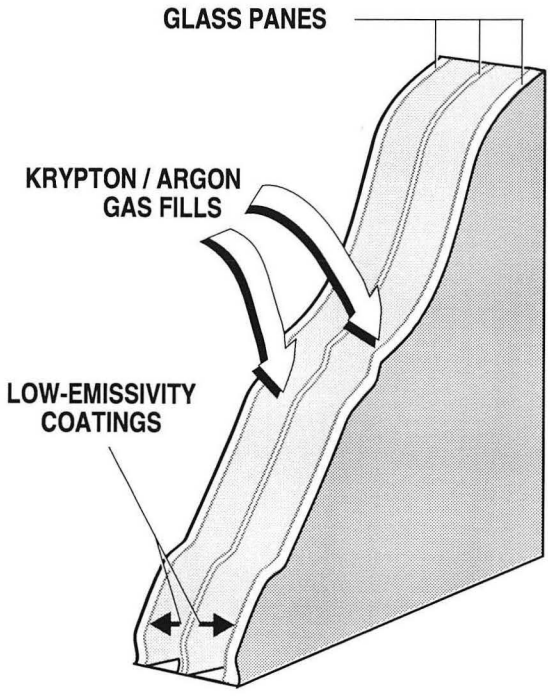
Our initial goal was to develop a clear understanding of the heat transfer mechanisms in windows and identify the technical opportunities for reducing those gains and losses. In cold climates, low-emissivity coatings allow sunlight to enter while reflecting back to the interior the long-wave infrared radiation that accounts for more than half the heat loss. Although the principle of how these coatings work was then understood, no U.S. manufacturer had yet developed a commercial product. At the time, there was no market demand (the benefits were unclear to purchasers), and it appeared impossible to produce coatings of high quality at low cost.

LBL awarded subcontracts to several firms to develop prototype coatings and new, low-cost, thin-film deposition processes. The performance of the coatings was tested at LBL and new computer models were developed to determine the best use of the coatings in the overall window system.

Encouraged by these efforts, by 1980 several large manufacturers were actively involved in low-emissivity window development, making major investments in manufacturing systems for new coatings. Initial product introductions in 1981–82 by a few innovative firms stimulated major manufacturers to offer products of their own. Second-generation products emerged that had greater durability and suitability for a wider range of climates. They were tested at LBL to demonstrate their market potential. By the mid 1980s, virtually every window manufacturer was offering low emissivity (low-e) windows. By 1987, low-e windows claimed 17% of window sales (180 million square feet per year).

Laboratory analyses at LBL showed that the next step to improve window energy efficiency for cold climates was to eliminate the air inside the double-paned insulating unit, replacing it with low-conductivity gas (such as argon). LBL simulation tools, as well as laboratory and field test data, helped convince manufacturers to incorporate this technique into their product and to inform purchasers that this was a reliable, cost-effective product. Double glazings with both low-e coatings and gas fills lose only 50% of the heat lost by conventional double glazing.

Although substantial efficiency improvements had been achieved, leading manufacturers were interested in pushing the technology further. Analysis suggested that windows with specific thermal and solar gain properties would perform so well that they would have a lower winter heating load than the best insulated walls. LBL staff developed a new "superwindow" concept for a multiple glazed window using two low-e coatings and a new krypton gas fill. LBL teamed with five manufacturers and suppliers (Andersen, Cardinal IG, Owens-Corning Fiberglas, Pella, and Southwall Technologies) and the Bonneville Power Administration to convert this window concept into commercial prototypes. Within two years, one participating manufacturer introduced the first commercial "superwindow" to the market.



"Superwindow" concept, based on multiple glazing, low-emissivity coatings, and gas fills.

Spectrally selective glazings are a recent variant on low-e coatings. Designed for hot climates, they work by selectively filtering out solar heat gain while minimizing the loss of visible light transmission. This advance means potential additional savings in the Sunbelt states and in commercial buildings where cooling loads should be reduced without loss of useful daylighting. In some cases, downsizing the cooling systems (made possible by reduced cooling loads) can offset the added cost of the more efficient windows.

Energy and Environmental Benefits

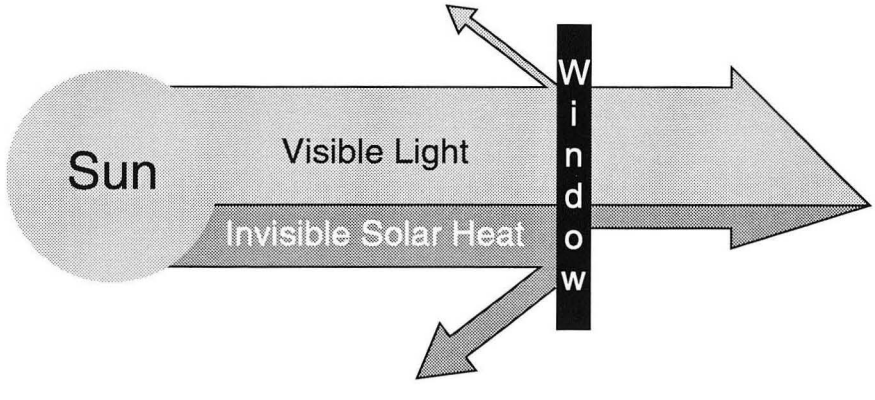
In 1990, the low-e market share rose to about 25%, and in 1993, it reached 36%, The widespread availability of ratings and labels—a development in which LBL plays a lead technical role—should help further accelerate market penetration of more efficient windows.

The cumulative energy savings attributable to advanced window coatings installed as of 1993 was $760 million. Based on energy savings "in the pipeline," i.e., for low-e-coated windows installed as of 1993, businesses and consumers will ultimately save $400 million (*net* of their extra capital investment), which will grow to $17 billion for technologies installed through the year 2015. These enormous savings were leveraged by a cumulative DOE investment through the early 1980s of just $3 million. The environment will also benefit from the use of advanced window coatings: In 2015, energy savings from advanced windows will allow us to avoid the emission of 71 million tons of CO_2, 157,000 tons of SO_2, and 142,000 tons of NO_x.

The Future

Advanced coating technology will lead to "smart windows" by the year 2000. A smart window uses a dynamic coating whose optical properties change from clear to reflective in response to a small electrical current. In partnership with industry, LBL scientists have developed promising prototypes with good performance. In homes, these windows will combine energy efficiency (by reducing solar heat gain and winter-time heat losses) with better comfort and privacy. In the office of the future, smart windows will control solar loads while admitting daylight, allowing electric lights to be dimmed with electronic ballasts.

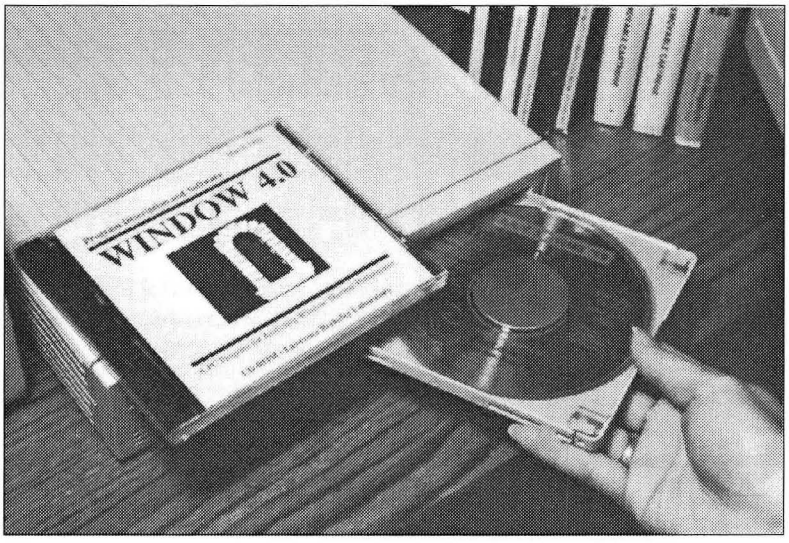
Toward this end, ion-beam technology developed in LBL's Accelerator and Fusion Research Division is being redirected by LBL's Windows Group to improve energy-efficient window coatings. These ion-assisted processes result in coatings with superior optical properties, longer lifetime, and lower cost. These devices were previously used as sources of particles in accelerators and more recently for some semiconductor processing steps like ion implantation of dopants.



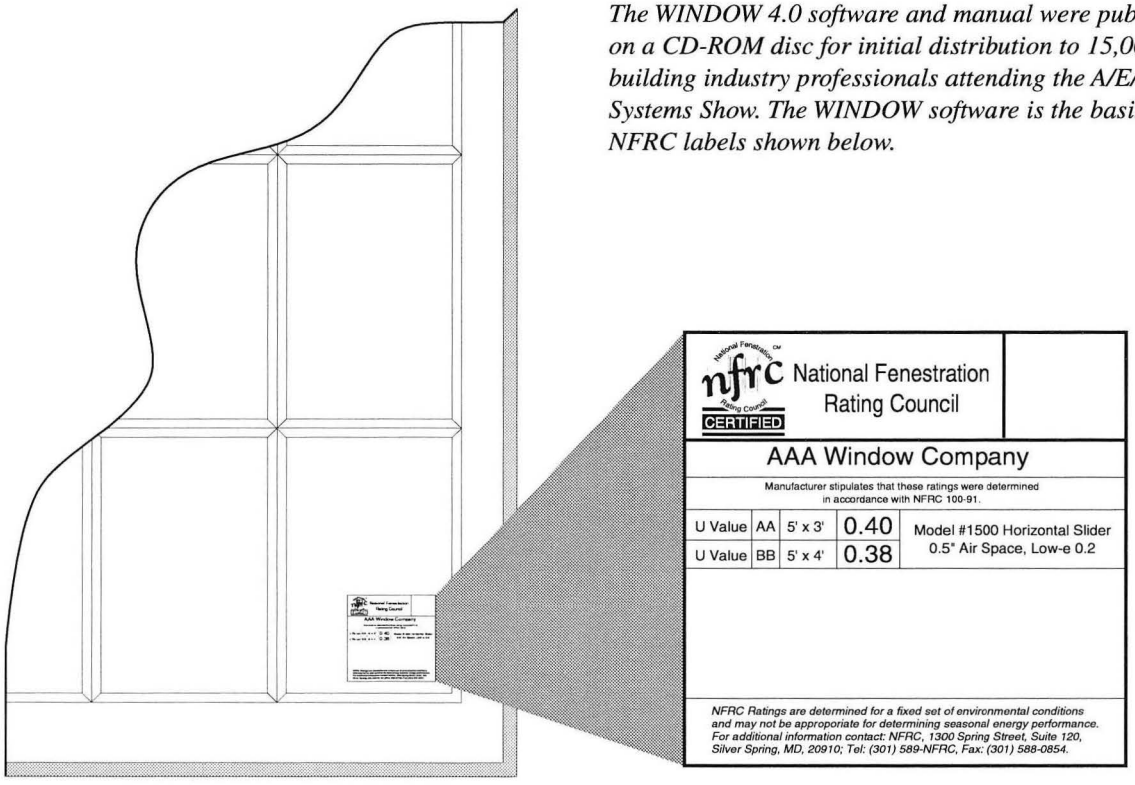
Spectrally selective glazing transmits high levels of visible light while reflecting invisible solar heat.

Labels to Make Windows Clearer

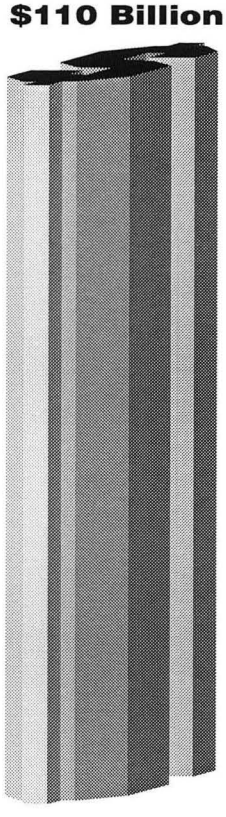
Purchasers of windows are confronted with many difficult decisions. New window features and technology add value, but builders and building owners have little interest in confusing technical details—they simply want to know how the products compare in total performance. In 1989, LBL began working with the window industry, utilities, and state agencies to create a new organization, the National Fenestration Rating Council (NFRC). The goal of the Council is to develop labels for windows that accurately and simply rate their overall performance. LBL has taken the lead in working to develop cost-effective accurate technical procedures for the NFRC, which uses LBL's WINDOW program as the primary rating tool. In 1993 California became the first state to require that all windows sold have an NFRC label.



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 shown below.



SETTING THE STANDARD FOR ENERGY EFFICIENCY



Residential consumers spend $110 billion each year on energy for appliances and heating and cooling equipment. At LBL, our energy policy work includes developing and analyzing appliance standards, many of which have become law. These standards have already saved U.S. consumers $1.9 billion and will result in a $58 billion savings, net of extra up-front costs, by the year 2015. The cumulative federal investment has been $50 million—just one one-thousandth of the benefits realized by consumers. Extending these standards to commercial-sector products can pay even higher dividends.

The DOE national laboratories have supported public policy efforts by serving as a key resource for legislators seeking definitive, independent data and technology assessments. As part of this effort, LBL has become the national center for appliance standards analyses. New generations of appliances have been spawned by these efforts. In addition to saving energy for consumers and the nation, these standards help make U.S. manufacturers more competitive in the global marketplace.

LBL's program provides the technical, economic, and manufacturer-impact analyses on which DOE bases mandatory standards that now apply to all major U.S. appliances: air conditioners, clothes washers and dryers, freezers, furnaces, heat pumps, refrigerators, televisions, and water heaters. In addition to technology research, LBL has provided DOE with pivotal support for understanding how the market functions and how certain market barriers to energy efficiency warrant legislative measures such as standards and labeling. Representatives from many countries come to LBL for guidance on developing their own appliance standards.

LBL monitors emerging technologies, identifying those developments that enable commercially viable improvements in appliance efficiency. For inclusion in proposed standards, new technologies must reduce the total life-cycle cost of buying and operating an appliance, while maintaining or increasing the level of service provided.

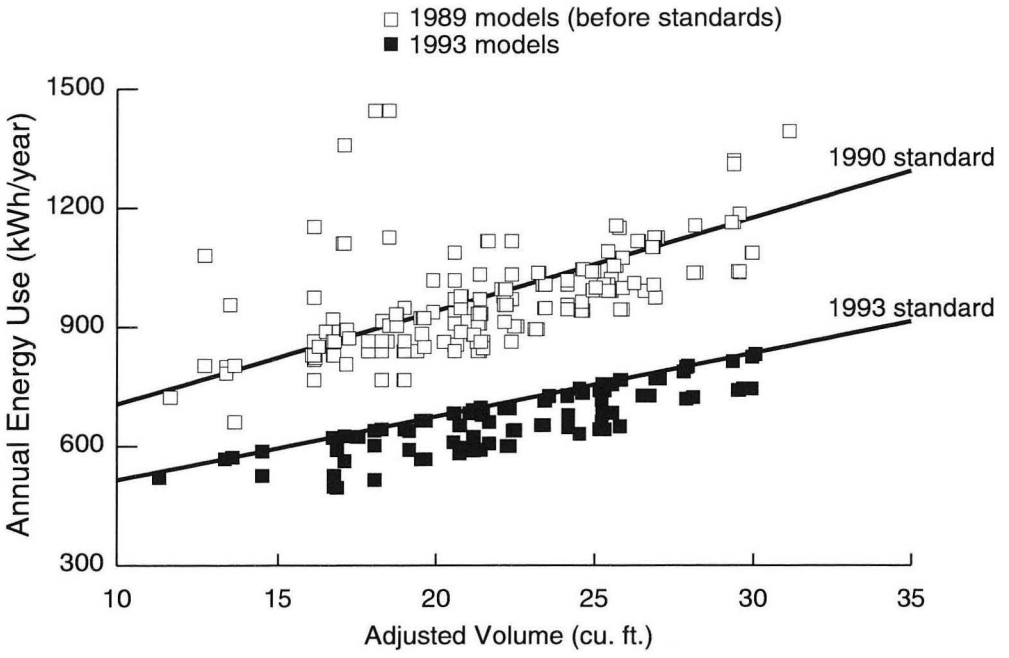
Energy and Environmental Benefits

DOE has invested about $50 million in standards. This sum includes development of test procedures, technical analyses, the administrative costs of public hearings, publication of laws and supporting documents, and program management.

Current appliance standards have already saved consumers $1.9 billion in energy costs and will ultimately save them $58 billion (the lifetime savings of units installed between 1990 and 2015, *net* of the extra investment costs). Coincidentally, U.S. consumers will avoid having to pay for the construction of eighty 250-megawatt electric power plants. These standards yield a benefit-to-cost ratio of almost 2.5 for consumers—energy savings are 2.5 times greater than the up-front cost premium paid for the appliance.

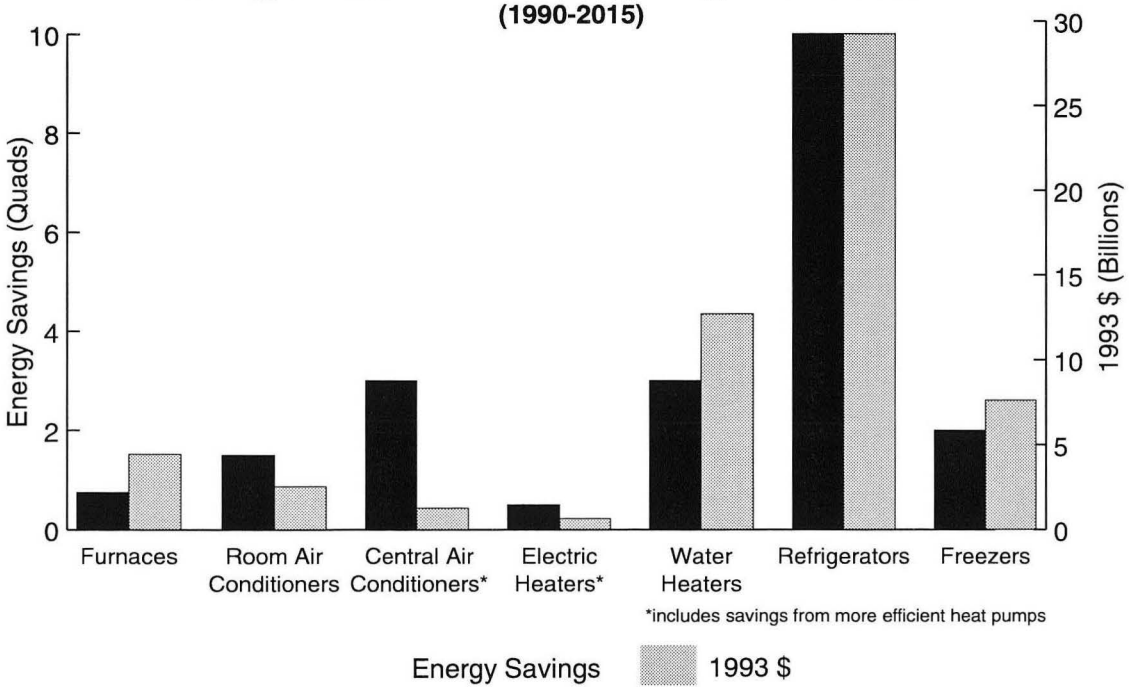
Appliance standards yield sizable environmental benefits as well. In 2015, these standards will enable us to avoid emissions amounting to 53 million tons of CO_2, 111,000 tons of SO_2, and 108,000 tons of NO_x. (These savings assume that chlorofluorocarbons will be phased out of refrigerators and freezers beginning in 1996.)

Refrigerator Standards Eliminate Many Inefficient Models



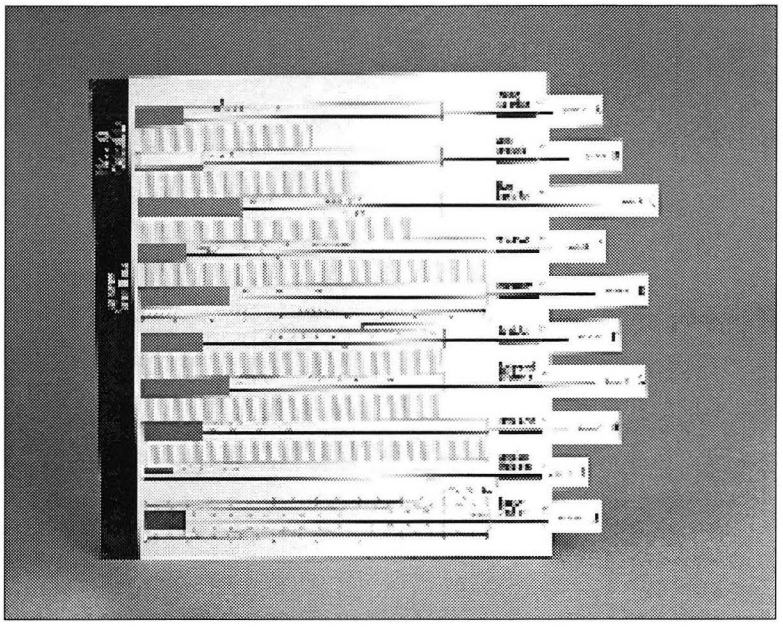
The two sets of data reveal the dramatic impact of appliance standards. The 1990 refrigerator standard eliminated many models sold on the market as of mid 1989. None of the pre-1990-standard models met the forthcoming 1993 standard. By 1993, however, some products beat the standard by as much as 15%. 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.)

Energy and Economic Benefits of U.S. Appliance Standards (1990-2015)



Standards for the Residential Building Envelope

About half of all residential energy is used for heating and cooling. Although improving the efficiency of air conditioners and furnaces is important, for optimal savings the building's envelope must also be considered. For more than ten years, LBL has provided technical support to efforts by government and industry to develop building energy standards and guidelines.



Between 1980 and 1983, LBL researchers created a large database of energy consumption in prototypical new houses in 45 U.S. locations using the DOE-2 program. We then converted this technical information into "Energy Calculation Slide Rules" that could be used by the general public. This project, conducted for DOE's Affordable Housing through Energy Conservation Program, won the 1984 *Progressive Architecture* award for research.

Recognizing in 1986 the new importance of personal computers, LBL converted this database into a simple computer program, PEAR (Program for Energy Analysis of Residences). PEAR gave builders and architects a fast and accurate method to estimate heating and cooling energy needs for any location in the U.S. LBL also gave the database to Pacific Northwest Laboratory (PNL) researchers, who were developing the mandatory building energy standard for federal buildings (known as COSTSAFR), and to ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers), to provide the technical basis of ASHRAE's 90.2 Residential Energy Standard, completed in 1993.

In 1987, LBL became a PNL subcontractor, charged with updating the PEAR database for PNL's flexible computer tool, ARES (Automated Residential Energy Standards), which can generate custom energy budgets for many locations in the U.S. In addition, LBL has distributed several hundred copies of the PEAR program to home builders, energy offices, and government and utility organizations. We have also used the databases in our forecasting and policy analysis efforts.

USE ARROW KEYS TO MOVE THE CURSOR (▶ ◀ ▲ ▼),<Space> TO EDIT, ? FOR HELP
<PgDn> FOR NEXT SCREEN, <PgUp> FOR PREVIOUS SCREEN, (End) TO QUIT

GENERAL INPUT		CONSERVATION MEASURES	
State.....	GEORGIA Keywd.	Ceiling Insulation.....	11.0 R-Val
City.....	ATLANTA Keywd.	Roof Color.....	DARK Keywd
Prototype.....	1S Keywd.	Wall Insulation.....	0.0 R-Val
FoundationType.....	SLAB Keywd.	Wall Mass Location.....	NONE Keywd
		Wall Color.....	DARK Keywd
Floor Area.....	1548.0 sq.ft.		
Wall Perimeter.....	166.0 ft.	Foundation Insulation.....	NONE Keywd
Cross Wall Area....	1328.0 sq.ft.	Floor Insulation.....	0.0 R-Val
North Window Area	38.5 sq.ft.	Window Layers.....	1 Pane
South Window Area	38.5 sq.ft.	Window Sash Type.....	PLAIN Keywd
East Window Area	38.5 sq.ft.	Window Glass Type.....	REG Keywd
West Window Area	38.5 sq.ft.	Window Movable Insulation.	NONE Keywd
Run Name	BASE CASE	Infiltration.....	1.0 AC/hr

HEATING ENERGY 749.67 THRM. (0.00) COOLING ENERGY 2968.69 KWH. (0.00)

The U.S. still does not have a uniform building energy standard, although standards exist for federal buildings and federally assisted housing, and an increasing number of states have residential energy standards. The ASHRAE-90.2 residential energy standard was approved in 1993 after a nine-year effort. Although it has no legal force, this standard will be influential as it represents the consensus of much of the building industry. Consequently, many states may be motivated to adopt or adapt it, particularly those that have no standards. LBL will continue to provide technical support for the development and implementation of residential building energy standards.

The Future

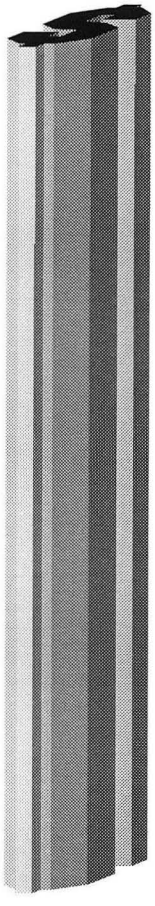
Built into the national legislation for establishing appliance standards are provisions to periodically revise and update them. As technology continues to advance, and economic conditions change, existing standards become obsolete and potential avenues for new savings are created. DOE recently proposed new standards for eight appliance products: water heaters, fluorescent ballasts, room air conditioners, pool/spa heaters, mobile home furnaces, non-ducted heating equipment, ranges and ovens, and televisions. LBL analysis has shown that the proposed standards would save as much money and energy as all existing standards and would result in an actual *reduction* in total residential energy demand—despite the projected growth of the buildings stock. LBL will continue to provide technical support for this process.

LBL is spearheading new efforts to establish efficiency standards for systems used to distribute cooling within residences (i.e., duct systems). Our efforts include conducting technical analyses to support stricter codes for duct installation and leading an ASHRAE effort to standardize efficiency determinations for residential thermal distribution systems. The California Institute for Energy Efficiency is an important partner with LBL in this work.

National energy policy is just beginning to apply efficiency standards to nonresidential uses. LBL has analyzed ballast standards and is working on standards for lighting in commercial buildings and small motors. LBL has been given the task of assessing new technologies specified in the Energy Policy Act of 1992.

LBL is helping DOE evaluate the technology and policy options for the nonregulatory development and commercialization of new energy-efficient products. Innovative "market-pull" approaches and major provisions of the Climate Change Action Plan will implement this Congressional mandate. Many new programs are partnerships with industry and utilities; others build on the buying-power of federal, state, and local governments to help create or expand markets for energy-saving products.

$208 Billion



TOOLS FOR BUILDING DESIGNERS

Operating residential and commercial buildings in the U.S. costs consumers almost $210 billion each year. New technologies can reduce this cost, but they can be optimally deployed only with proper design tools. LBL incorporates the knowledge gained over a decade and a half of building energy research into new computerized analytical and design tools, the most important of which is DOE-2. About 5% of commercial floorspace today is designed with DOE-2. Based on a recent survey of major users of the program, DOE-2 facilitates a savings of $85 million annually in energy bills—about $1.9 billion cumulatively for U.S. buildings constructed with the help of DOE-2 through 1993. California building standards (developed using DOE-2) save consumers almost $1 billion each year. Efforts to make existing tools more user friendly are projected to boost their application to 50% of all buildings.

The nation's building industry is immense, but lacks the tools for optimizing energy efficiency. Thus, in the mid 1970s, LBL accepted the challenge of developing a computer program for analyzing energy use in buildings. The resulting program—DOE-2—calculates hourly building energy use and cost from information about the building's construction; climate; operation; heating, ventilating, and air-conditioning systems; and utility rate schedule.

During 1975, the U.S. Energy Research and Development Administration (ERDA, which later became the Department of Energy), and the California Energy Commission (CEC) agreed that a comprehensive building energy analysis computer program was needed to develop and support energy efficiency standards. In response to this need, LBL started a joint project with three national laboratories—LBL, Los Alamos National Laboratory (LANL), and Argonne National Laboratory (ANL)—to develop the Cal-ERDA code, later to become DOE-1 and then DOE-2. LBL led the effort, in charge of overall coordination and development of the basic user interface and simulation code. The objective was a whole-building energy analysis program that could simulate all building types in all climates, a program that was unbiased, well documented, and open to public scrutiny. ANL wrote the user documentation. LANL added active and passive solar simulation capabilities, and developed the engineering documentation. A private company, Consultants Computation Bureau, assisted in developing the interface (Building Description Language) and the programming. A steering committee with representatives from DOE, the California Energy Commission, and industry guided the development effort. To provide a program that would be technically sound and widely accepted, we based DOE-2 on algorithms developed by ASHRAE, a respected industry organization. We also used methods from earlier programs like NECAP, NASA's Energy Cost Analysis Program, and TWO-ZONE, a residential analysis program developed by LBL.

The first version of DOE-2 was released in 1978. Fulfilling its original intent, it became the basis of four major standards: the California Title 24 building energy efficiency standard, considered the most advanced in the world; the national Building Energy Performance Standard, which was abandoned during the Reagan administration before it could be implemented; the DOE/ASHRAE 90.2 standards for residential buildings; and the DOE/ASHRAE 90.1 standards for commercial buildings, which are now voluntary and will become mandatory in each state, as required by EPACT.

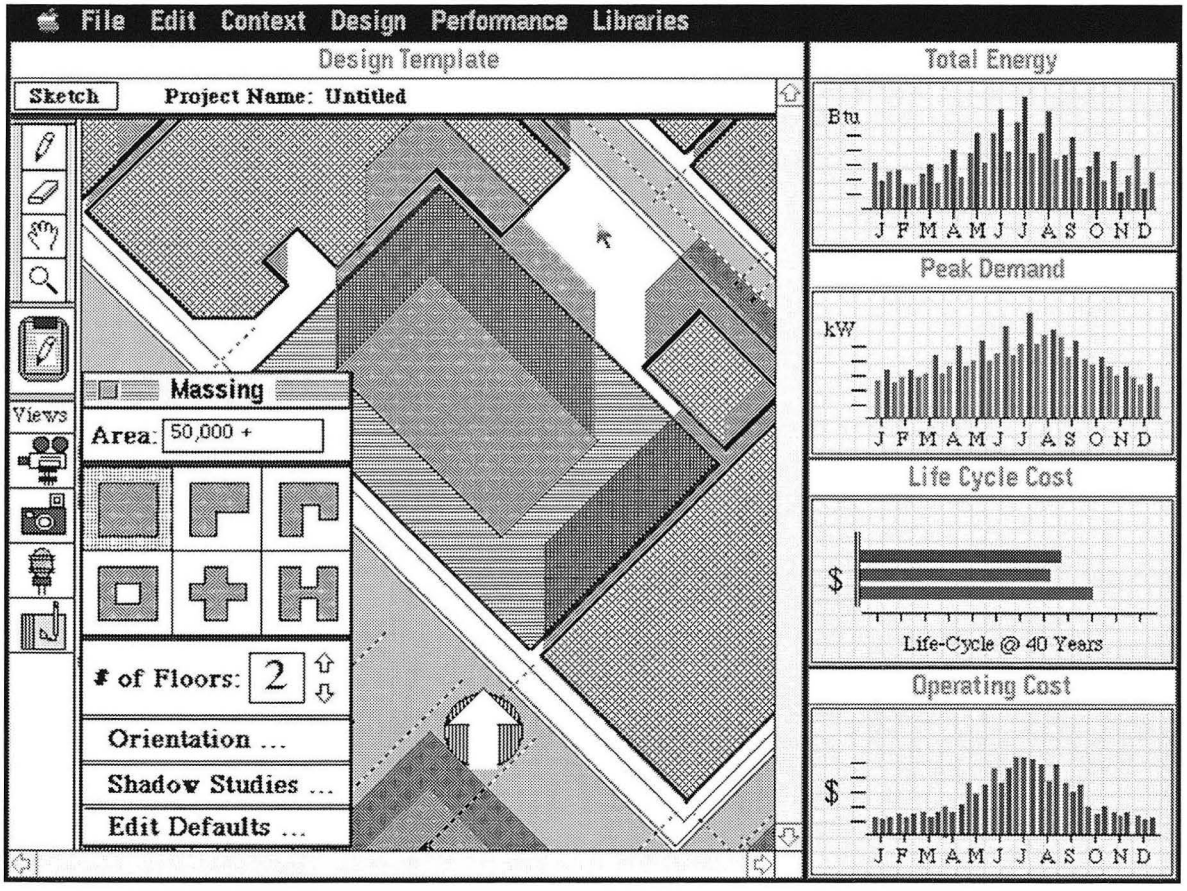
In addition, DOE-2 is now widely used for the design of energy-efficient buildings and for impact analyses of new technologies. During the past ten years, DOE, the private sector, including utilities like Southern California Edison, Pacific Gas & Electric, and Bonneville Power Administration, and utility organizations such as the Electric Power Research Institute and the Gas Research Institute have supported improvements to DOE-2.

The California Energy Commission estimates that the annual energy cost savings from the Title 24 standard, which was designed with DOE-2, was $420 million in 1985, $970 million in 1992, and will increase to $1.6 billion in 1999.

The cumulative California savings are estimated to be: $4.9 billion (1985-1992), and $13.8 billion (1985-1999).

Today there are 1000 DOE-2 user organizations in the U.S. and 42 other countries. In the U.S., DOE-2 is used by 70% of the utilities promoting energy efficiency with demand-side management programs. Most commonly used in the design of new buildings, DOE-2 has also found a niche in the retrofit arena. Identifying energy retrofits for the Audubon Society's national headquarters was one prominent application.

A number of firms—ADM Associates (Sacramento, CA), Gable Dodd Associates (Berkeley, CA), ITEM Systems (Seattle, WA), Finite Technologies (Anchorage, AK), ERG International (Golden, CO), and Partnership for Resource Conservation (Boulder, CO)—have converted DOE-2 into a PC-based program or developed and marketed ancillary software.



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 the BDA.

Leveraged Energy and Economic Savings

Although not a hardware technology, DOE-2 directly facilitates energy savings in building projects where it is applied. Results of a 1991 survey showed that users help design or retrofit a total of 326 million square feet of buildings each year with DOE-2 (equivalent to about 5% of all commercial construction), at an average energy savings of 20%. The energy cost savings in these buildings is about $85 million/year. Buildings designed with the help of DOE-2 over the past decade have achieved about $1.9 billion in additional energy savings. For compari-

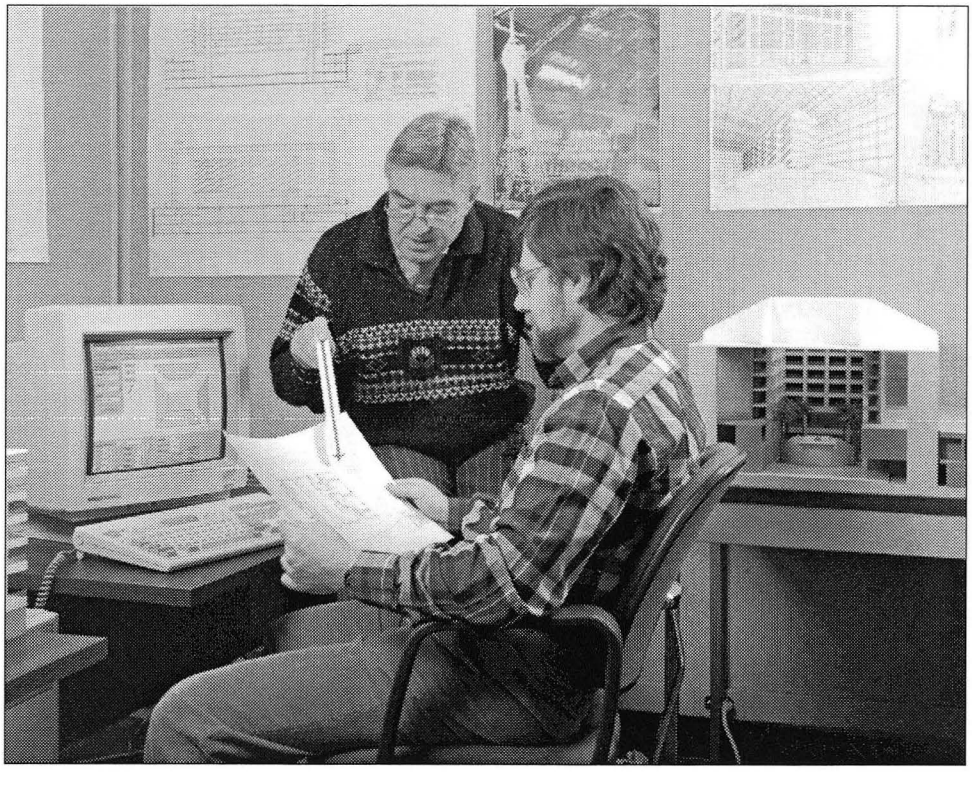
son, the total investment in development and support of DOE-2 to date is about $15 million. Based on a cost of $0.10 per square foot, the delivery of design and technical services using DOE-2 is now a $30-million annual industry.

The Future

PowerDOE—a new PC-based and user-friendly interface for DOE-2—is being developed by a joint private/public team with support from Electric Power Research Institute (EPRI), utility companies, the California Energy Commission, and the U.S. Department of Energy. A consortium of utilities and government agencies in Canada recently selected PowerDOE as the basis for its next-generation design tool. Current research efforts are focused on developing and commercializing PowerDOE (for new and retrofit applications), which will increase ten-fold the number of DOE-2 users.

Another goal is to expand DOE-2 use among architects (the program is currently used mostly by engineers) by coupling it to a Building Design Advisor (BDA) software package now under development at LBL. Building designers will be able to use BDA to incorporate energy-efficiency considerations throughout the building design process, assisted by built-in, context-dependent advice on options to improve performance.

LBL has proposed linking this energy design tool with an indoor environment model so that indoor air quality and energy efficiency can be evaluated early in the design process.



MEASURING BENEFITS AND MARKET IMPACT

Various metrics help assess the impact of the four research programs. One is market penetration. As shown in the table below, electronic ballasts have achieved a 23% market share in 1993, while low-emissivity and spectrally selective glazings have captured a 36% market share. Residential equipment standards have achieved full market penetration for the products regulated. DOE-2 design software is used to design about 5% of new commercial floorspace and as an aid in developing mandatory local standards and voluntary national guidelines applicable to all buildings. Two other metrics are the retail value of products and services and the value to consumers of the energy saved.

Market Impact of Energy-Efficient Products and Design Tools Aided by LBL Research and Development[a]

	Electronic Fluorescent Ballasts	Advanced Window Coatings	Residential Equipment and Appliance Efficiency Standards	DOE-2 Buildings Design Tool[e]	Total	Percentage of U.S. Buildings Emissions
MARKET IMPACTS						
Total R&D Investment (current $ millions)	$3	$3	$50	$15	$71	
Product market share in 1993 (% of units sold)	23%	36%	virtually all	5%		
Product market share in 2015 (% of units sold)	77%	79%	virtually all	50%		
Incremental value of product sales in 1993[b] ($ millions, 1993 $)	$200	$630	$1,500	$35	$2,365	
Incremental value of product sales in 2015[b] ($ millions, 1993 $)	$1,300	$1100	$2,200	$300	$4,900	
CONSUMER BENEFITS ($ millions, present value in 1993 dollars)						
Value of energy savings "in the bank" as of year-end 1993[c]	$400	$760	$1,900	$1,900	$4,960	
Lifetime value of savings for technologies installed through 1993[c]	$1,000	$6,300	$7,900	$2,800	$18,000	
Lifetime value of savings for technologies installed through 2015[c]	$18,400	$37,000	$100,000	?	$155,400	
Value of annual energy savings in 2015[c]	$5,100	$5,300	$6,000	?	$16,400	
NET present value of technologies installed through 1993[d]	$700	$400	$4,400	$2,000	$7,500	
NET present value of technologies installed through 2015[d]	$12,800	$17,400	$58,500	?	$88,700	
ENVIRONMENTAL BENEFITS						
Carbon dioxide emissions avoided in 2015 (million tons/year)	73	71	53	?	197	8%
Sulfur dioxide emissions avoided in 2015 (thousand tons/year)	157	157	111	?	425	6%
Nitrogen oxide emissions avoided in 2015 (thousand tons/year)	144	142	108	?	394	3%

Savings from lighting, window, and appliance standards do not, in general, overlap. Savings gained by using DOE-2 are achieved by a variety of building technologies.

a. The time frame adopted for each case spans the first year of a product's use through the year 2015. Savings are computed with respect to a dynamic business-as-usual baseline (i.e., efficiency improvements attained without the new technology).

- For electronic ballasts, the baseline is core-coil magnetic ballasts and T12, 40-watt lamps up to 1990 and energy-efficient magnetic ballasts and T12, 34-watt lamps (mandated by standards) from 1990 forward. The efficiency case reflects electronic ballasts and T8, 32-watt lamps—3500 hours-per-year use.
- For windows, the baseline is dual-glazed windows for the residential sector and tinted single-glazed windows for the commercial sector. This baseline tends to underestimate savings in the early years for households (when single-glazed windows are still prevalent). Significant savings are attributed to daylighting made possible by the higher visible light transmission achieved by the advanced glazings in commercial buildings. No savings from gas fillings or from stick-on retrofit coatings are assumed.
- For appliance standards, the baseline is a market projection of price-driven improvements in energy efficiency. Minimum efficiency standards for each appliance are then implemented in the year called for by legislation.
- For DOE-2, the survey of major DOE-2 users indicated that they achieve 20% energy savings beyond what would have been the case without DOE-2. DOE-2 (or its descendants) will eventually be used for at least 50% of commercial construction, and energy performance standards will continue to be tightened based on analysis performed with DOE-2. However, it is too difficult to estimate the prospective savings. These savings would also include parts of the impacts shown here for windows, lighting, and equipment.

b. Retail value is based on the *incremental* cost of the efficient technology compared to the baseline technology, e.g., comparing a $10 magnetic ballast with an $18 electronic ballast yields an incremental cost (retail value) of $8 per ballast. Market share is the percentage of all related product sales (e.g., ballasts) captured by the efficient technology or service shown. As the industry matures, low-e coatings decline in cost from $4 per square foot in 1985 to $1.20 per square foot in 2015. Spectrally selective coatings drop from an initial cost of $5.60 per square foot in 1995 to $1.70 per square foot in 2015. The retail value of DOE-2 design services is estimated based on a fee of $0.10 per square foot

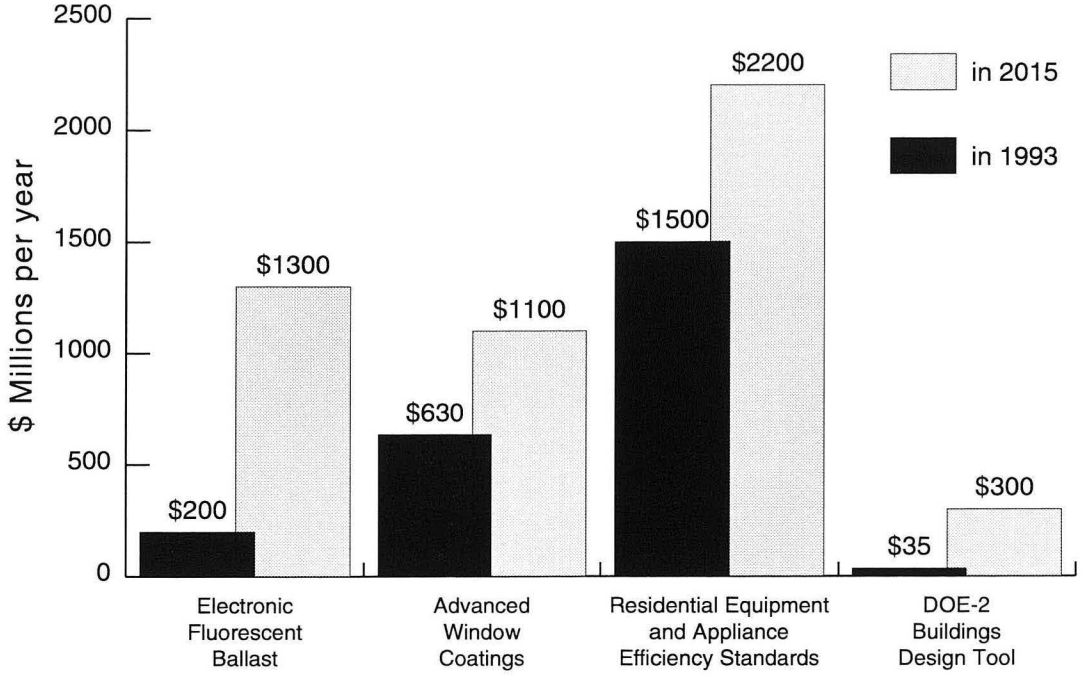
c. Value of energy savings, excluding added cost of efficient equipment. A 7% real discount is used to convert savings to a present value in 1993 dollars.

d. Present value of energy savings, net cost of efficient equipment. A 7% real discount is used to convert savings to present value in 1993 dollars. Net present values include lifetime savings of technologies installed in each year. The extra efficiency investment ("retail value") for buildings designed using DOE-2 to date is inferred based on a three-year payback; values for the future have not been estimated.

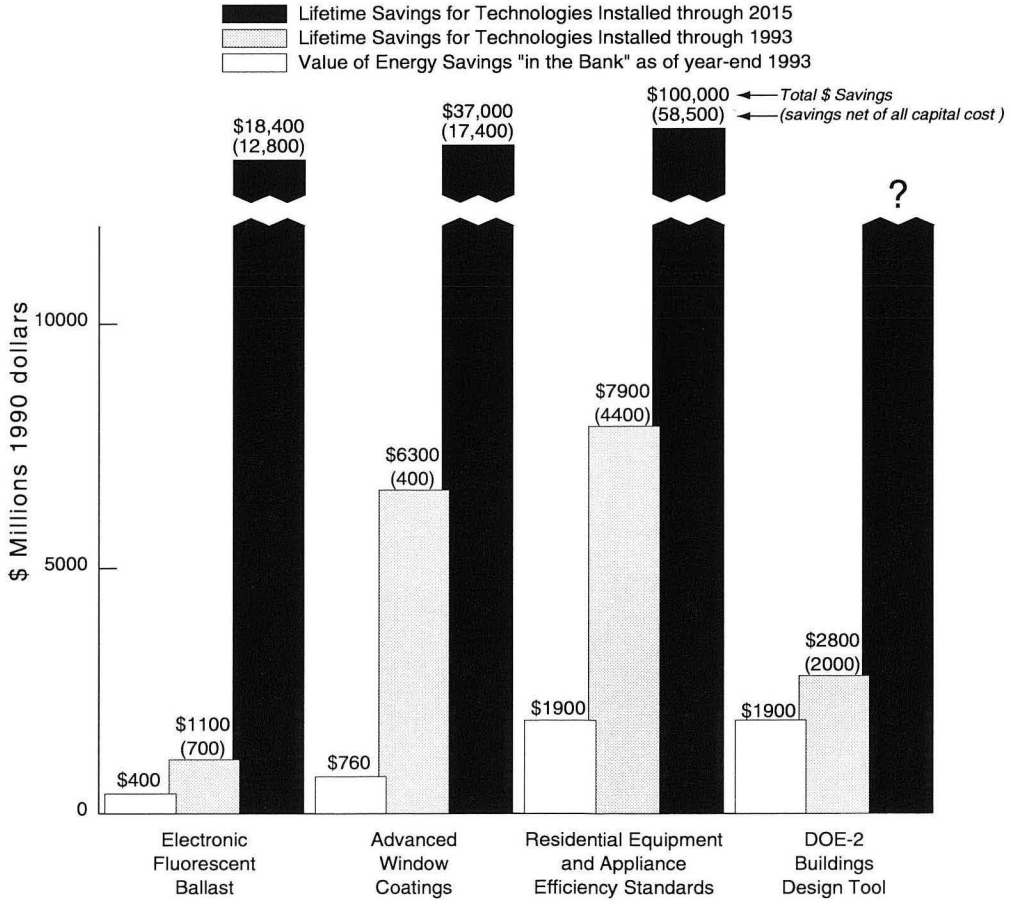
e. Excludes savings achieved by building standards based on DOE-2 analyses.

Market Creation

Value of Energy-Efficient Products and Design Tool Services in the U.S. Market

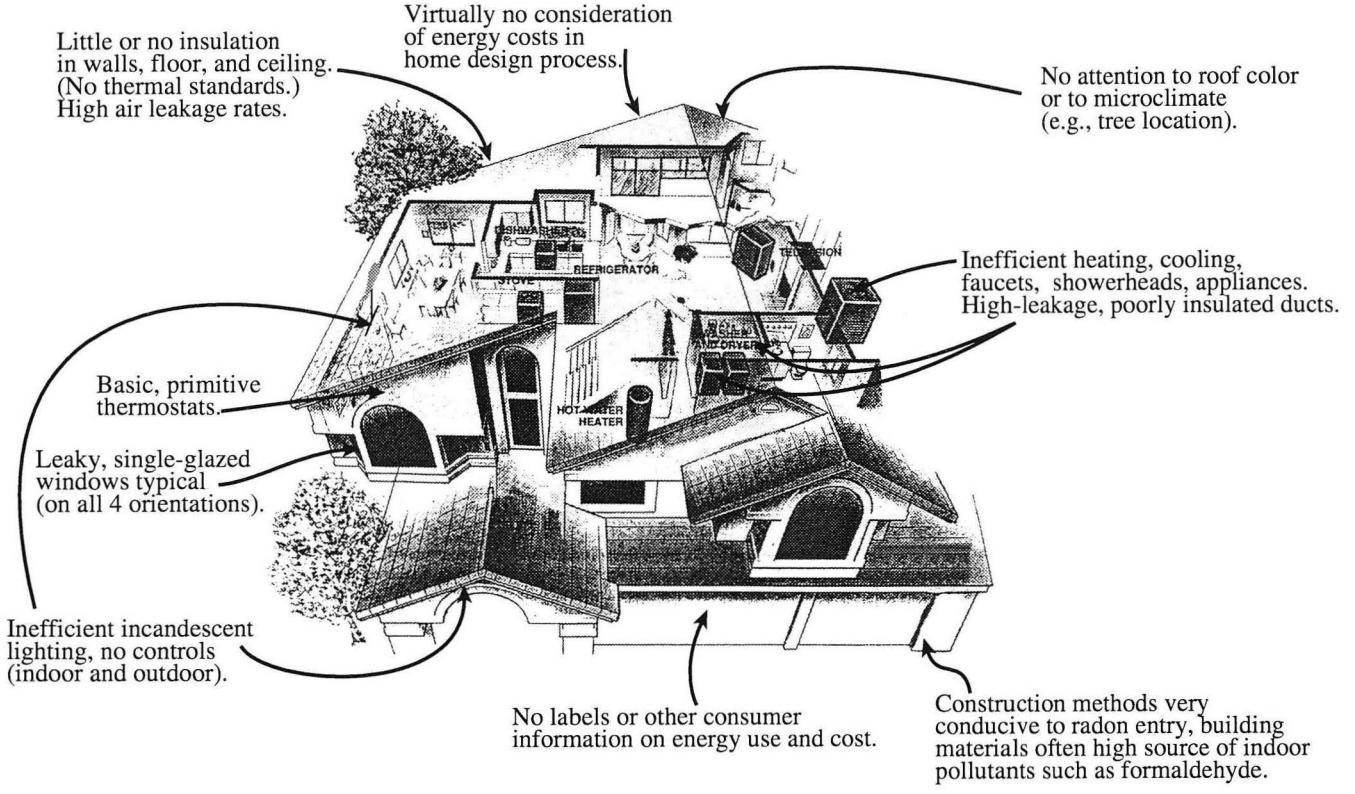


Economic Benefits



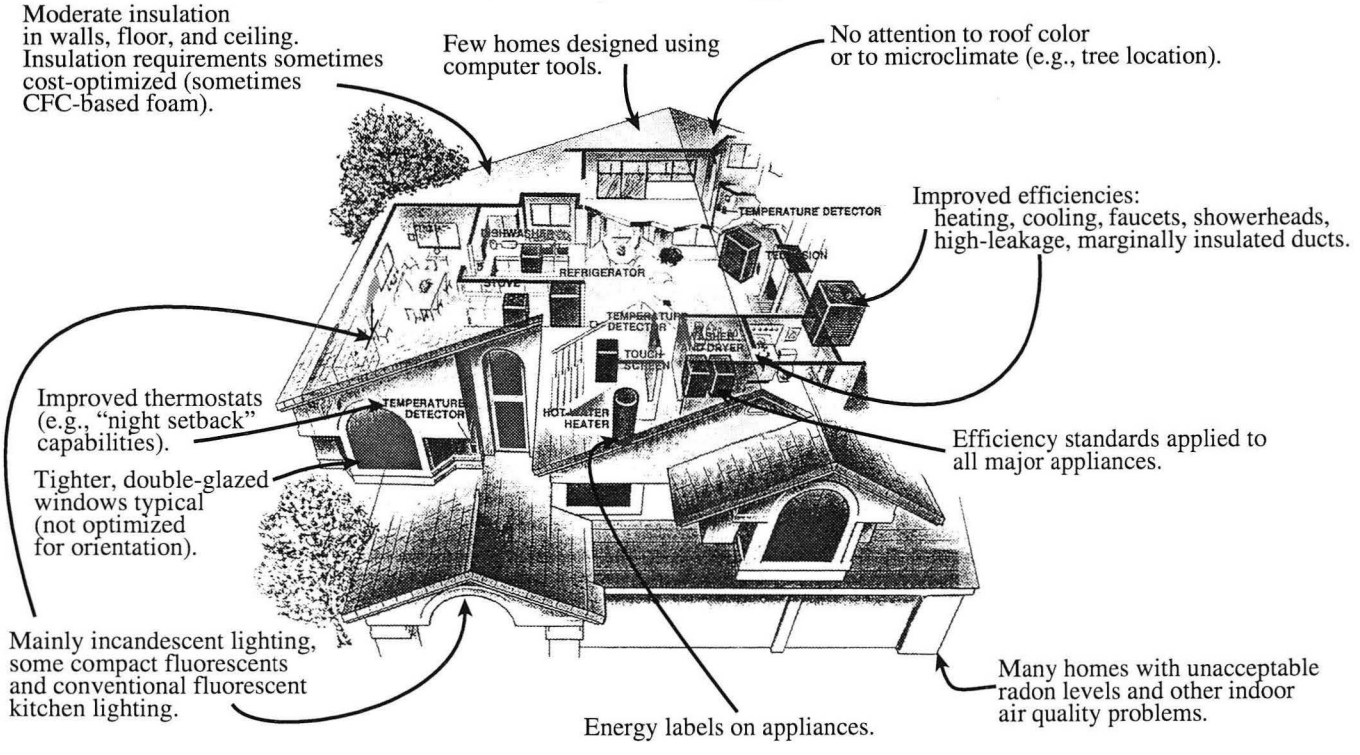
Pre-Oil-Crisis (1973) Home

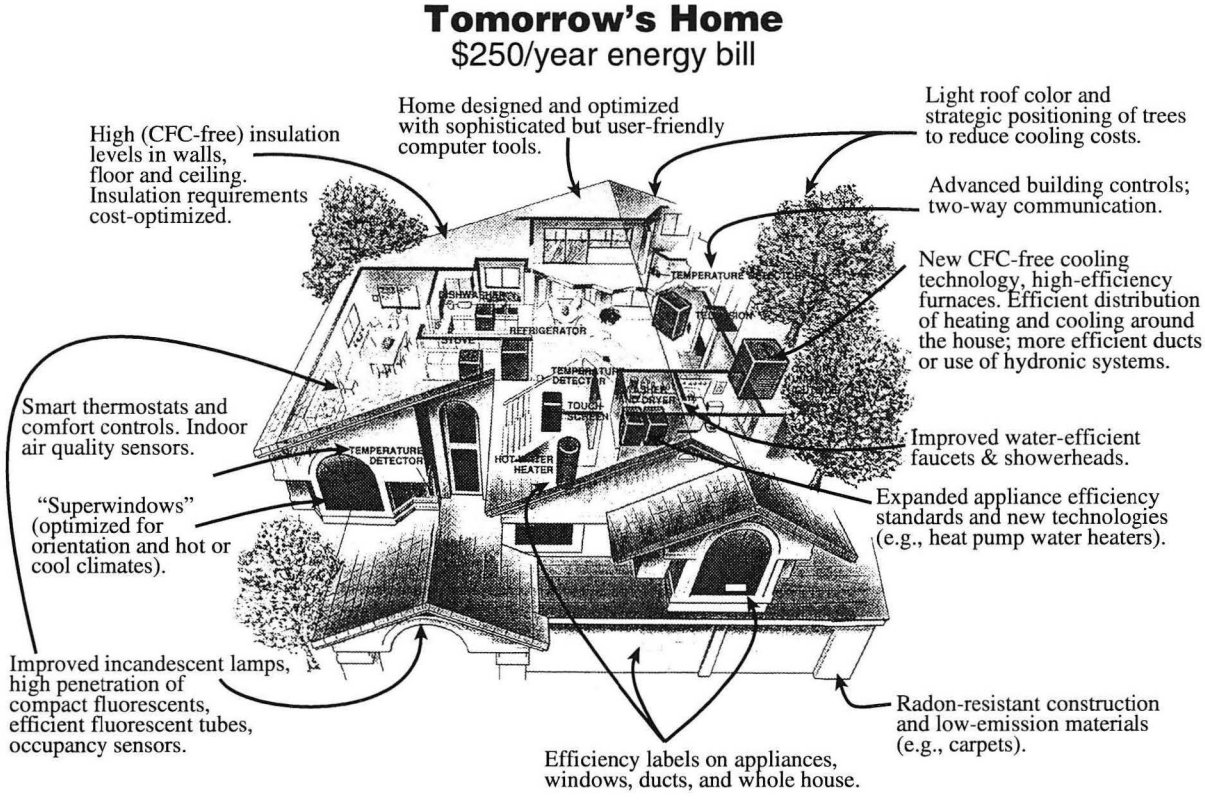
$2000/year energy bill



Today's Home

$1000/year energy bill





In most cases, energy efficiency is "invisible" and needn't affect the appearance of a home. The three illustrations depict the energy attributes of pre-oil-crisis (1973) vintage home, today's home, and the home of tomorrow. Many of the improvements shown relate to LBL research described in this report (i.e., technologies, standards, design tools, and indoor air quality considerations). Most of these technologies and strategies are being applied to commercial buildings as well.

LBL'S BROADER ROLE IN THE BUILDINGS ENERGY ARENA

World Wide Web—

The Center for Building Science now has a World Wide Web (WWW) home page easily accessible from the LBL home page. The WWW makes it possible to send and receive text, video, audio, and all types of graphics (including photographs) over the Internet. Mosaic is the user-friendly interface that makes it possible to view and manage this information. Through WWW and the Mosaic browser, Internet users can access LBL's hypertext documents, gopher databases, library catalog, publications list, and Quicktime movies. All that's required is a networked computer (Mac, PC, or UNIX) that runs Mosaic. The WWW address (universal resource locator or URL) is "http://eande.lbl.gov/Building_Science.html".

From the Center's home page, users can view, save, and print text and graphics that describe ongoing projects at the Center, browse all the issues of our newsletter, and view and perform keyword searches on the Center's publication list. All information is linked through hypertext, making it easy to find related topics or articles.

Although best known for our R&D and technology spin-offs to industry, LBL's buildings energy research programs are distinguished in other areas. 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 both locally and internationally.

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. In addition, LBL publishes research results on the Internet.

Education is 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 laboratories. 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.

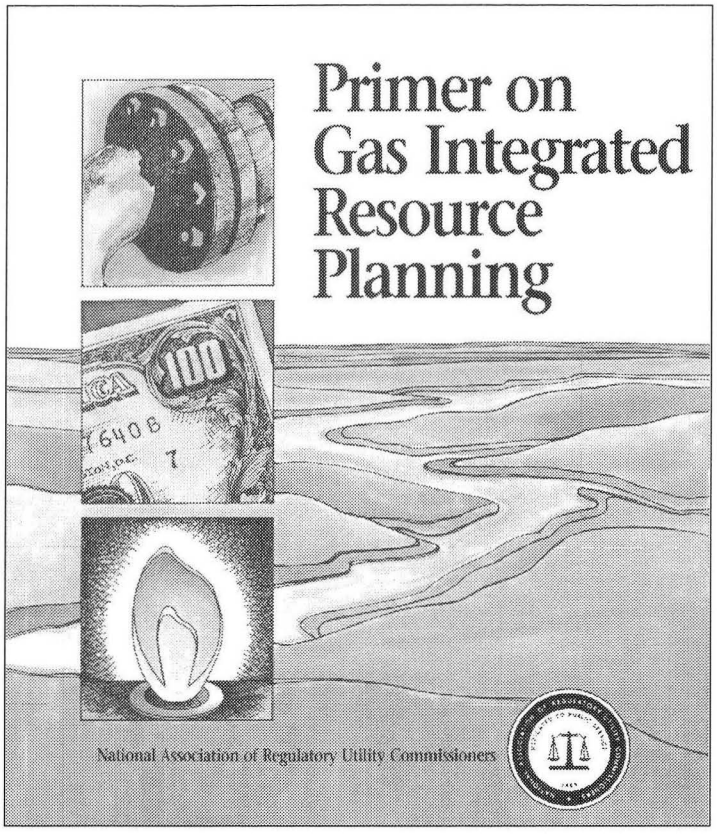
After the Cold War, in a Warming World

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 national laboratories. The U.S. produces one-quarter of the world's "greenhouse-gas" emissions. Laboratory efforts that have focused on achieving emissions reductions include participating in the prestigious National Academy of Sciences "Mitigation Panel" on climate change and contributing to the Administration's Climate Change Action Plan (the "cool communities" action was developed at LBL). We also assist DOE in developing and implementing its international energy-policy activities related to climate-change mitigation.

Partnering with Electric and Gas Utilities

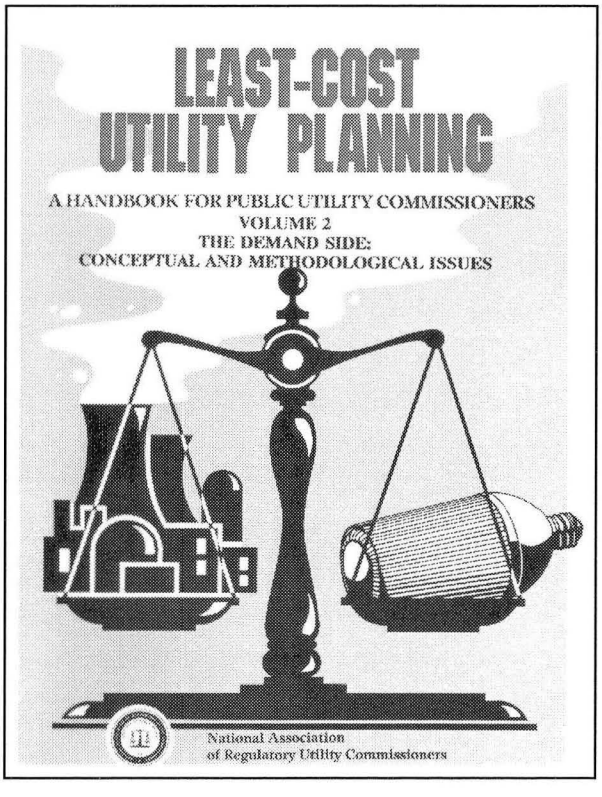
The nation's electric and gas utilities spend $2–3 billion each year on energy-efficiency programs. Their investment leverages another $1 billion in private investment, and creates jobs and markets for new, energy-efficient technologies. With utility companies expected to spend a total of $20 billion on energy programs during the 1990s, the cumulative effect of these programs will be to offset the 20–30% of expected load growth during the decade with economic benefits of $40–$50 billion. An emerging possibility is a slowdown in utility demand-side management (DSM) efforts, which may hamper their ability to achieve these projections. Whether or not utilities meet their goals will depend

on regulatory trends across the country and other driving factors, including environmental goals and new competitive dynamics among energy suppliers.



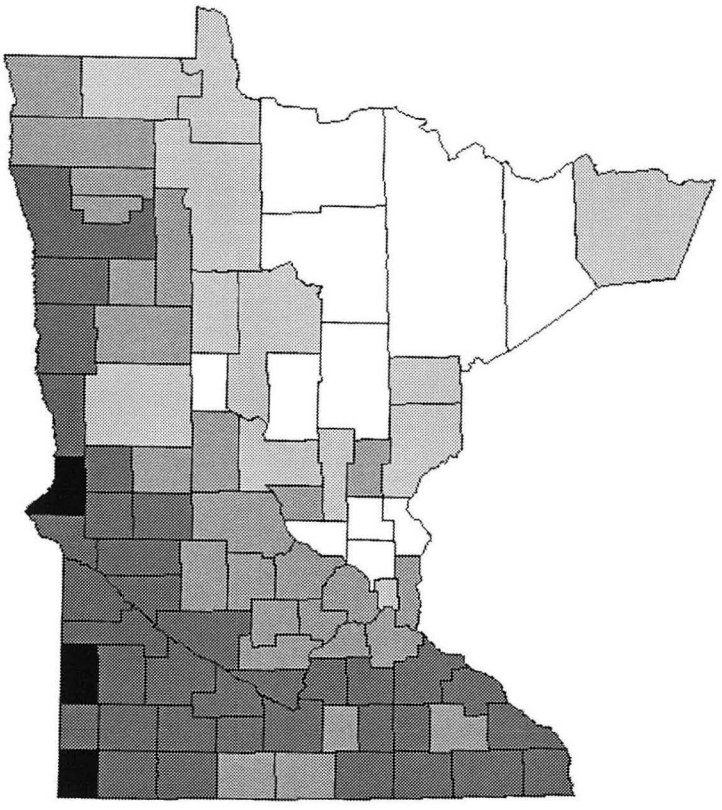
For some years, LBL has worked closely with a number of utility companies, their national trade associations (the Electric Power Research Institute and the Gas Research Institute), and especially, state regulatory utility commissions and the National Association of Regulatory Utility Commissioners. LBL's energy-efficiency programs have aided in the development of new methodologies of energy-demand forecasting, evaluation of the impact of energy-efficient technologies on utilities, and market-based programs that utilities initiate to deploy those technologies. LBL researchers pioneered the procedures for making "conservation potential" studies, which are now used routinely by many utilities around the nation. Other work has supported the national trend toward utility regulatory reforms 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. 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.



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 twenty-four 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, EPRI, international groups, and industry provided the technical basis for EPA's successful "Energy Star" labeling program for office equipment.

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).



Estimated geometric mean radon concentration by county for Minnesota. Darker shades indicate higher indoor radon levels. Homes in unshaded counties have estimated concentrations below 2.5 pCi/L (picocuries per liter); darkest counties are greater than 5.5 pCi/L.

Enhancing Indoor Air Quality

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 save 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—creating a staggering healthcare cost of about $1 billion annually. Although exposure to air pollutants is dominated by indoor exposure, almost all research and regulatory attention is on outdoor air quality. Indoor air pollutants are responsible for premature deaths in 10,000 lung cancer patients annually (caused by radon), 1,500 deaths due to accidental carbon monoxide poisoning, and 10,000 related medical visits. Each year exposure of young children to environmental tobacco smoke causes an estimated 150,000 to 300,000 lower respiratory tract infections, such as bronchitis and pneumonia. Asthma—with its $6.2 billion annual U.S. healthcare cost—is exacerbated by poor indoor air quality. The indoor environment also affects the rates of transmission of important infectious diseases such as influenza, tuberculosis, and the common cold. More than 20 million cases of influenza occur annually in the U.S.

Unless properly conceived and implemented, some energy-saving measures can create indoor air quality problems. Mitigating these problems can waste energy—excess ventilation without heat recovery, for example. LBL recognized that both energy efficiency and the quality of the indoor environment must be optimized, and in the 1970s, LBL established the Indoor Environment Program. With one of the world's premier research groups on the environmental effects of indoor radon, this program has provided basic insights into how radon gas from the soil enters homes. (After cigarettes, radon is the second largest cause of lung cancer.) LBL researchers use geographic information systems to pinpoint areas 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 taxpayers than the "shotgun" approach of trying to measure and take action in every home.

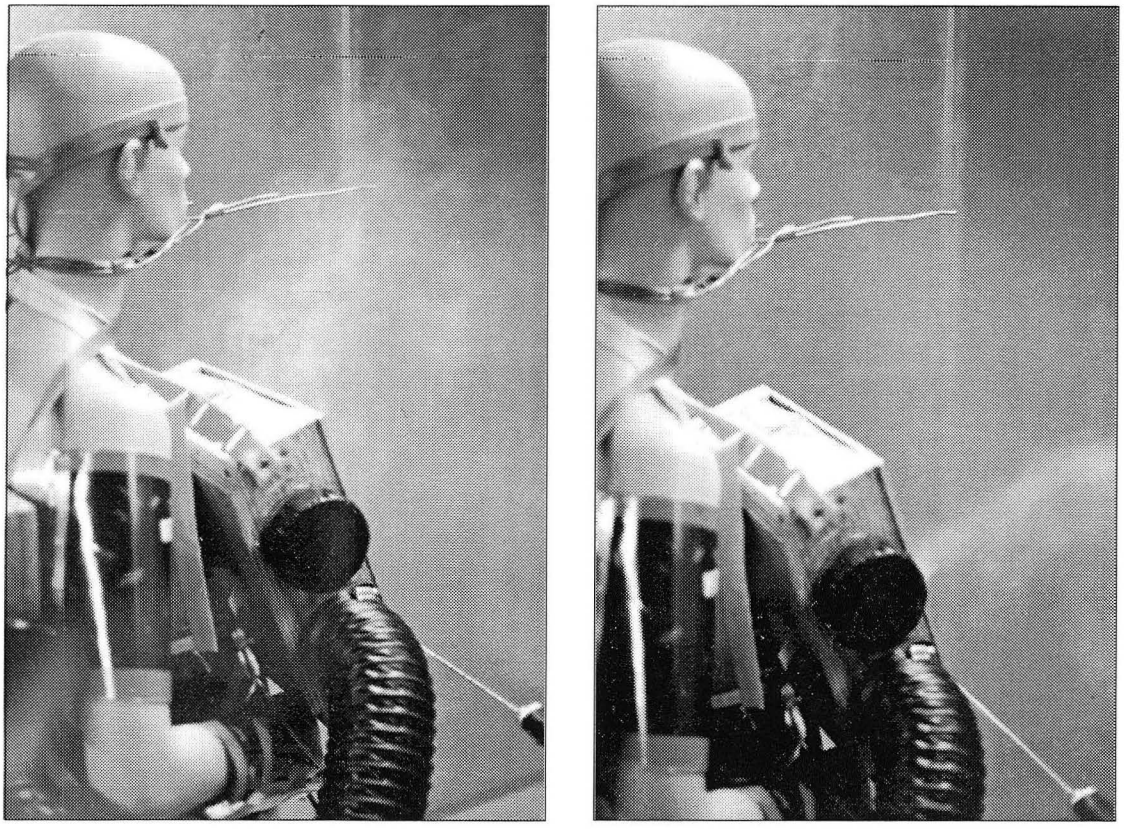
The well-known but poorly understood "sick building syndrome," which may affect as much as 20% of all new office buildings, has also been studied at the Laboratory. Among the conclusions of our research: occupants in structures with air conditioning suffer a greater number of building-related health symptoms than occupants in structures with natural ventilation. In a separate project, LBL researchers have documented the connection between particles in the indoor air and the premature failure of electronic devices.

The productivity of the U.S. work force increasingly depends on fast and dependable electronic communication and electronic equipment. Electronic equipment failures can impede work performance and engender costly repairs. There is substantial evidence that the deposition of aerosols on circuit boards (leading to electronic short

circuits) and the action of corrosive gases on electronic circuits and electrical contacts is a major cause of failures in electronic equipment.

As an example of the economic significance of these failures, consider the telephone industry. The annual cost of circuit-board failures in the 300,000 telephone switching offices of the U.S. is approximately $1 billion, and about 20% ($200 million) of these failures can be traced to indoor air pollution. Many of these failures are attributed to indoor environmental factors, although typical indoor environmental conditions are maintained in the telephone switching offices. Possible methods for reducing failures include improved filtration, better temperature and humidity control, and automatic control of ventilation based on outdoor particle concentrations.

In addition to illuminating the basic processes influencing indoor air quality, LBL's program stimulates and accelerates 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 significantly reduce spraybooth worker exposure to pollutants 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).



The full-size mannequin in these photographs simulates a worker in a spray booth facing the exhaust filters. In experiments designed by an LBL researcher, smoke was released in front of the mannequin to simulate the spraying of paint in the booth.

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. The program's leader has recently been appointed Chair of the U.S. Environmental Protection Agency's Science Advisory Board's Indoor Air Quality/Total Human Exposure Committee.

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, LBL researchers helped the Department of Housing and Urban Development to track energy use and identify ways of reducing the $1 billion per year energy bill in public housing. Their research also led to new legislation that removes barriers to energy efficiency in public housing and establishes new business opportunities for private energy service companies. In our most recent effort, we are members of an elite team charged with carrying out the "Greening of the White House" project, unveiled by President Clinton on Earth Day 1994. LBL researchers have provided technical support to DOE's own In-House Energy Management Program, which has achieved annual savings of approximately $155 million in DOE energy bills. The Laboratory supports the Federal Energy Management Program (FEMP) and will play 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 working with the Federal Aviation Administration to identify advanced energy-efficient technologies and modeling tools that can upgrade the work environment in the nation's air traffic control towers and facilities, improving comfort, visibility, and equipment reliability, and thereby improving air travel safety.

At an Earth Day 1994 celebration, President Clinton extols the benefits of a compact fluorescent lamp, while a CFL production employee looks on. Also in attendance were Vice President Al Gore and eight cabinet members. Photo by Marvin Jones, courtesy Osram Sylvania, Inc.

Providing a Helping Hand to States

LBL has worked with individual states for two decades. 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.

From its inception, the energy-efficient buildings program at LBL has been particularly attentive to California energy issues. In the early 1970s, Laboratory scientists scrutinized projections that electricity demand in California would grow at six percent per year—a rate that would require dozens of new electric power plants by 1985. We maintained that increased energy efficiency could cost-effectively reduce that growth rate to only one or two percent, generating vast economic savings for the state. Many disagreed with this position, but it proved true. Thanks in part to energy efficiency policies, programs, and standards, California has built no large power plants in a decade and none are currently planned.

LBL researchers have provided technical support to the California Energy Commission almost since its inception, 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 supporting 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 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 (ACT^2). 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 of California's energy utilities, the California Energy Commission, the California Public Utility Commission, the University of California, and DOE. Each year CIEE funds and coordinates $5 million of research at California universities and university-affiliated DOE laboratories, focusing on technologies crucial to the state and the region. The Institute emphasizes applications that simultaneously improve end-use efficiency and lower utility operating costs.

International Activities

Many of the DOE efficiency-related activities have spun off beneficial ideas and information to other countries. Several 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 computer program is used in 42 other countries and has been used to develop building energy efficiency standards in, among others, 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 special projects focus on Russia and China, which 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 U.S.

LBL's international group helps 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. 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 the developing country emissions scenarios used by the prestigious Intergovernmental Panel on Climate Change. LBL is participating in DOE's Country Studies Program. This initiative grew out of the commitment made by the U.S. at the 1992 Earth Summit to help countries comply with the Framework Convention on Climate Change. The program is designed to help developing and transitional countries to (1) develop inventories of their anthropogenic emissions of greenhouse gases, (2) assess their vulnerabilities to climate change, (3) assess their ability to mitigate greenhouse gas emissions, and (4) formulate and evaluate response strategies for mitigating and adapting to climate change. LBL was selected to provide technical support for the third task—mitigation assistance—because of its substantial knowledge of the technologies, policies, and analytical methods for reducing greenhouse-gas emissions. In support of this activity, LBL brought together a technical support team of 30 researchers from academic, private, and government institutions experienced in global climate change issues. In addition to LBL, the team includes five U.S. national laboratories: Oak Ridge National Laboratory, Pacific Northwest Laboratory, Brookhaven National Laboratory, Argonne National Laboratory, and the National Renewable Energy Laboratory. This group's first project was a two-week, intensive, hands-on workshop attended by 60 representatives of the target countries.

In addition, we have established an informal program through which energy researchers from developing countries work at LBL on projects of mutual interest. Over the past ten years, more than 100 researchers have spent more than 50 person-years at the Laboratory on such projects.

FROM THE LAB TO IMPLEMENTATION

The Center for Building Science Applications Team

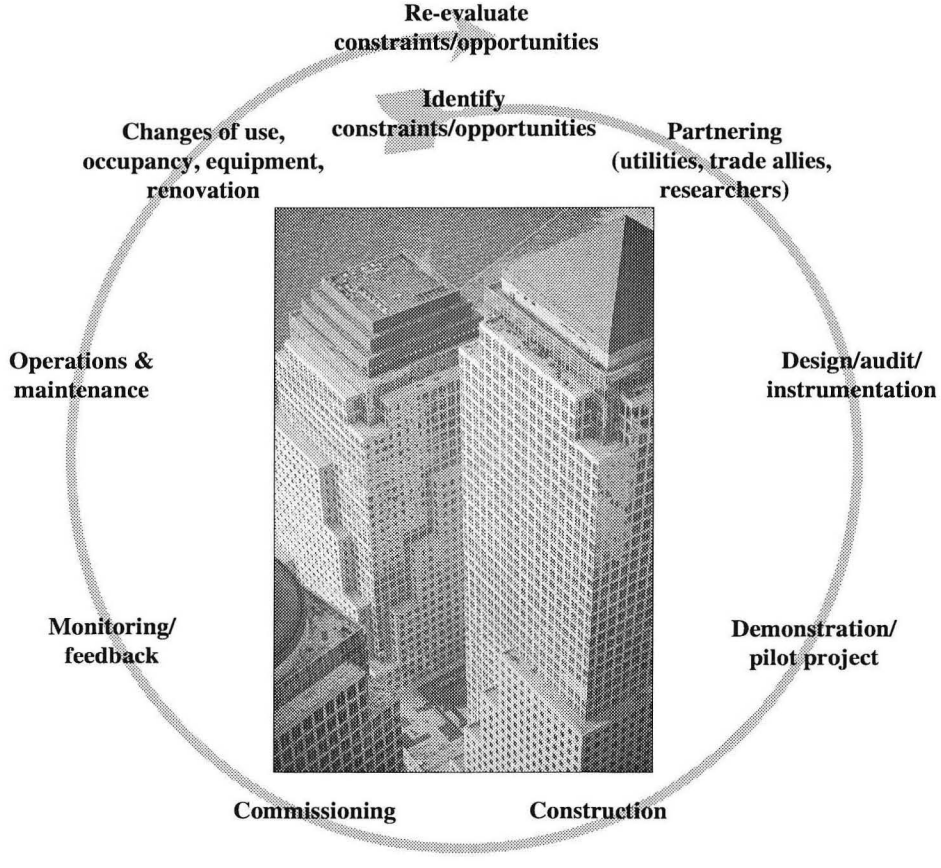
The Center for Building Science's Applications Team (the "A-Team") marshals LBL's unique capabilities and networks to conduct field projects whose purpose is to deploy advanced energy-efficiency and indoor environmental quality concepts in both the U.S. and overseas buildings sectors. The aims of the Team are to:

- *Demonstrate proven and emerging building technologies in order to accelerate their adoption by consumers and building professionals.*
- *Elevate professional standards of practice.*
- *Transfer new energy management methods and tools to the private sector.*
- *Provide feedback to the federal energy R&D planning process.*

The A-Team's philosophy is to apply an integrated approach to retrofitting existing buildings and designing new ones. This approach encompasses the various stages of a building life cycle as seen from the perspective of facilities management, addressing the areas of energy, illumination, comfort, and the indoor environment.

The A-Team assembles project teams from the 250-person staff in the Center's three research programs, LBL's In-House Energy Management Program (IHEM), other research organizations and laboratories, and private firms. The IHEM program managed a study and retrofit budget of $18 million through 1994 for LBL's own facilities, including project planning, financial analysis, engineering, procurement, construction management, commissioning, monitoring, and evaluation. One of IHEM's notable achievements was completion of DOE's first comprehensive performance contracting agreement with a private energy services company for retrofit of a laboratory building.

The Facilities Management Building Lifecycle



To accomplish its goals, the A-Team also makes use of its relationships with other professionals in energy-efficiency implementation from R&D centers across the country—government agencies, electric and gas utilities, state energy offices, manufacturers of energy-efficient technologies, and technical committees that define energy-related standards and guidelines.

Bridging R&D in Practice

The A-Team forges a new link between existing DOE building R&D activities and deployment initiatives. A-Team activities will benefit R&D program planners by providing improved feedback and recommendations for eliminating inefficiencies and missed opportunities during the implementation of new technologies and methods in the field. More specifically, the A-Team

- Develops, implements, and evaluates proven, cost-effective energy-efficiency measures in existing buildings.
- Assembles confidence-building demonstrations of emerging technologies and energy management practices not commonly used by building professionals.
- Develops and disseminates state-of-the-art field guidelines and protocols, for example, for measurement and verification.
- Demonstrates the potential for achieving energy savings while maintaining or improving indoor environmental factors influencing human productivity and well-being such as indoor air quality, lighting quality, and thermal comfort.
- Transfers design and application methods and tools to private-sector practitioners such as architecture and engineering firms that collaborate with the A-team.
- Supports energy savings performance contracting on a national level.

In the Field

The A-Team benefits private-sector building professionals by raising market awareness of the value of energy efficiency, for example, through high-profile demonstrations and independent verifications of performance and cost-effectiveness and by partnering with private-sector firms on specific projects. Feedback from these efforts is also valuable in product development and marketing.

A-Team services are available to federal agencies, utilities, states, regional or national efficiency program designers, and large public, private, or institutional building owners. To maximize their impact, the A-Team chooses projects selectively, emphasizing high-visibility, replicability, and the specialized services and resources possessed by LBL and project collaborators. Examples include creating a master plan for energy efficiency retrofits at the Presidio of San Francisco in cooperation with DOE and the National Park Service, conducting super-audits of the Federal Aviation Administration's air traffic control towers and other facilities, and investigating ways that California industries can reduce energy costs in their laboratory facilities.

AWARDS AND CITATIONS

National Fenestration Rating Council Technical Achievement Award - 1994

Dariush Arasteh

In recognition of exemplary contributions to the NFRC mission through outstanding scientific and technical achievement and leadership in the development of NFRC technical procedures.

Federal Laboratory Consortium Award for Excellence in Technology Transfer - 1994

Michael Siminovitch

Thermally efficient compact fluorescent downlights.

U.S. Department of Energy, Sadi Carnot Award - 1993

Arthur Rosenfeld

For lifetime achievement in the field of energy conservation and renewable energy.

U.S. Federal Energy Management Program Sustained Exemplary Service Award - 1993

LBL In-House Energy Management Program

National Research Council's Transportation Research Board Fred Burggraf Award - 1993

Jonathan Koomey, Deborah Schechter, and Deborah Gordon

Excellence in transportation research by researchers 35 years of age or younger. For the article entitled "Cost Effectiveness of Fuel Economy Improvements in 1992 Honda Civic Hatchbacks."

Federal Laboratory Consortium Special Award for Excellence in Technology Transfer - 1993

Stephen Selkowitz and Dariush Arasteh

Superwindows.

Popular Science Magazine's Best New Product Award - 1991

Dariush Arasteh, Stephen Selkowitz, Brent Griffith

Grand award in home technology category for development of gas-filled insulating panels.

PEW Charitable Trust Award - 1991

Ashok Gadgil

Award of $150,000 over three years, for work related to promoting energy efficiency in developing countries.

Energy Efficient Buildings Association Technical Award - 1991

Stephen Selkowitz

Recognizing exceptional technical contributions to energy-efficient buildings design and practice.

Federal Laboratory Consortium Special Award for Excellence in Technology Transfer - 1989

Fred Winkelmann, Ender Erdem, Kathy Ellington, Bruce Birdsall, Fred Buhl

For developing, documenting, disseminating, and supporting the DOE-2 program for simulating building energy use.

Citation from Progressive Architecture Magazine - 1989

Stephen Selkowitz, Dariush Arasteh, Michael Wilde, Bob Sullivan, Francis Rubenstein

For development of a Skylight Design Manual and accompanying software to help architects and engineers use skylights in a more energy-efficient manner.

American Physical Society's Leo Szilard Award for Physics in the Public Interest - 1989

Anthony Nero

For work on indoor radon, nuclear proliferation, and reactor safety.

ASHRAE Willis H. Carrier Award - 1988

Joseph Eto

For best presentation by an author under the age of 32 describing work using DOE-2 to study economic impacts of then-pending revisions to the ASHRAE standards for ventilation.

ASHRAE Crosby Field Award - 1988

Joseph Eto

For the best technical paper describing work using DOE-2 to study economic impacts of then-pending revisions to the ASHRAE standards for fresh air ventilation.

Federal Laboratory Consortium Special Award for Excellence in Technology Transfer - 1988

Stephen Selkowitz and co-workers

For developing and transferring to industry the WINDOW thermal analysis computer program.

U.S. Department of Energy, Sadi Carnot Award - 1988

Sam Berman

For contributions to the development of high-frequency solid-state ballasts and advances in energy-efficient windows.

American Physical Society's Leo Szilard Award for Physics in the Public Interest - 1986

Arthur Rosenfeld

For advancing energy-efficiency technologies.

Citation from Progressive Architecture Magazine - 1985

Stephen Selkowitz and co-workers

For developing the sky simulator that enables architects and engineers to realistically test daylighting designs.

Citation from Progressive Architecture Magazine - 1984

Ron Ritschard and Joe Huang

For developing energy calculating slide rules.

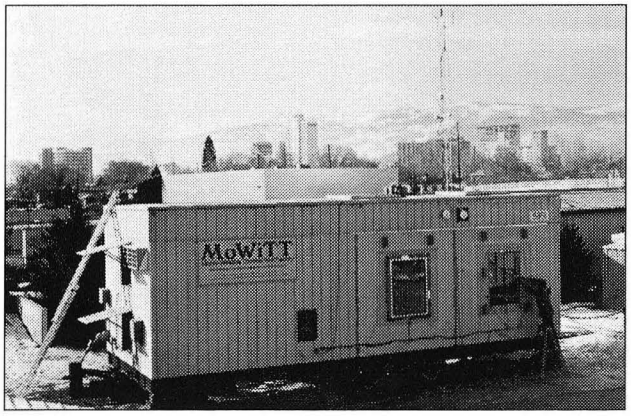
ASHRAE Willis H. Carrier Award - 1979

Stephen Selkowitz

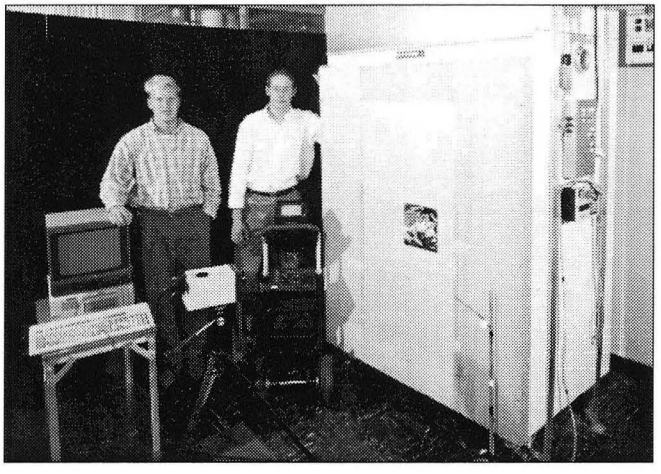
For best presentation by an author under the age of 32 of a paper describing advanced window system performance.

USER FACILITIES AND RESEARCH LABORATORIES

LBL's energy-efficient buildings programs operate several user facilities and research laboratories, some of which are available by arrangement to building industry professionals, architects, manufacturers, the academic community, and other national laboratories.

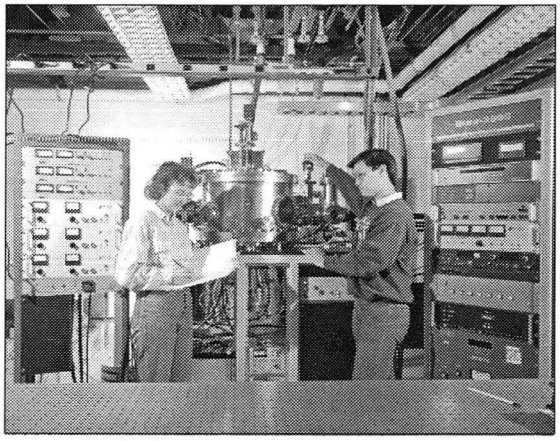


MoWiTT

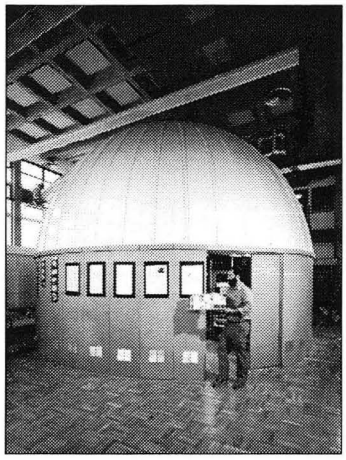


IR Thermography Lab

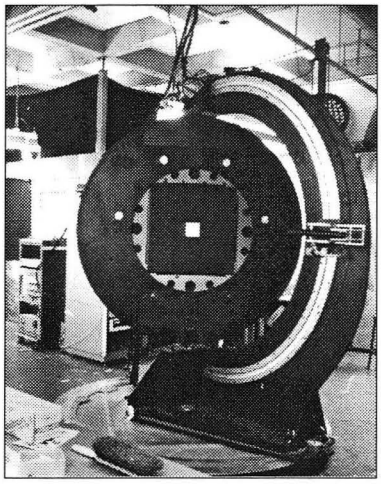
- ***The Energy-Efficient Fixtures Laboratory*** is dedicated to the development of optically and thermally efficient long-tube and compact fluorescent fixture systems. Testing devices characterize the thermal and photometric performance of fixtures and advanced compact fluorescent prototypes, and include temperature-controlled photometric integrating chambers and experimental plenum systems for studying the performance of recessed downlights using compact fluorescent lamps.
- ***The Integrating Sphere*** is used for relative photometry of light sources. The total lumen output of any source can be measured under standard thermal and electrical conditions. The sphere is used extensively by the LBL's Lighting Systems Group to measure the efficacy and lumen output of a broad range of light sources.
- ***The Infrared Thermographic Lab*** includes a high-resolution, infrared imaging camera, a computer processor/printer, and a cold/hot chamber to hold samples for testing. The camera system is portable and can measure surface temperatures that can be correlated to various heat loss or gain parameters. The IR camera is useful for assessing heat loss from existing buildings in the field as well as from building components and appliances in the laboratory.
- ***The Mobile Window Thermal Test Facility (MoWiTT)*** contains two highly instrumented, side-by-side calorimetric test chambers that are used to test the thermal performance of window and wall elements under actual outdoor conditions. The facility may be rotated to face in any direction and is currently located in Reno, Nevada, which experiences both summer and winter extreme climate conditions. The facility can directly measure solar heat gain and can determine window and shading system properties for a wide variety of solar control options. With 200 data channels collecting data every few seconds, MoWiTT can directly measure cooling load shapes on peak summer days with excellent time resolution. The facility can also be used to validate computer models and to compare various technologies in real time. Industry has used MoWiTT results to justify new product development.
- ***The Radon Test House,*** located in Richmond, California, is used for studies of the transport and behavior of radon progeny and indoor aerosols.
- ***The Environmental Chamber*** can be conditioned to maintain desired temperature, humidity levels, and ventilation rates. The facility is used by LBL researchers and collaborators for a variety of indoor air pollution studies such as assessing emissions from consumer products and building materials.



Thin Film Deposition and Characterization



Sky Simulator



Solar Heat Gain Scanner

- ***The Sky Simulator*** is a 24-foot-diameter hemispherical facility used to test daylighting performance in scale-model buildings under controlled and reproducible conditions. Computerized control of light sources within the hemisphere can create luminous distributions typical of clear, uniform, or overcast skies representative of any desired location, orientation, climate, and season on Earth. It can also be used as a sun simulator to test shading strategies in scale models up to 1.5 square meters in size. Light levels within the models are measured by 60 photosensors, and the measurements are used to predict daylight illuminance conditions in full-sized buildings. The facility is well-suited to test the effect of shading from overhangs, fins, awnings, shade systems, vegetation, and adjacent obstructions.
- ***The Solar Heat Gain Scanner*** is used to characterize the complex optical properties of shading systems such as venetian blinds. The system measures transmitted and reflected energy and light at all incidence and outgoing angles. The only facility of its kind in the U.S., it has become the basis for a new procedure to predict solar heat gain through shading systems. This work is cost-shared by DOE and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).
- ***The Thin-Film Materials Laboratory*** houses a wide range of apparatus to deposit and analyze thin-film, spectrally selective coatings for energy control purposes. The laboratory also includes spectrophotometers to measure solar, near IR, and far IR properties.
- ***The Geographic Information System (GIS)/Image Processing Laboratory*** has image processing software operating on a SUN SPARC workstation that runs image processing and vector-based and raster-based GIS software. A PC-based GIS system is also available.
- ***The Hypermedia Laboratory*** is used to develop design tools of the future that will not only have faster and better modeling algorithms but will also have vastly improved user interfaces incorporating new multimedia software and hardware capabilities. The ability to integrate data and text with advanced graphics, animation, sound, and video will enhance the value and usefulness of the next generation of design and analysis tools. The hypermedia computer lab has the equipment necessary for experimenting with these emerging technologies and prototyping and testing promising solutions. The laboratory has been used to develop several prototypes including an interactive computerized kiosk with videodisk for Southern California Edison.

KEY PUBLICATIONS

General

"Efficient Use of Energy: Part I - A Physics Perspective," W. Carnahan, K.W. Ford, A. Prosperetti, G. Rochlin, A.H. Rosenfeld, M.H. Ross, J. E. Rothberg, G.M. Seide, R.H. Socolow, *American Institute of Physics Conference Proceedings*, Vol. 25 (1975).

Supplying Energy Through Greater Efficiency, A. Meier, J. Wright, and A.H. Rosenfeld, University of California Press (1983).

"The Role of Federal Research and Development in Advancing Energy Efficiency: A $50 Billion Contribution to the U.S. Economy," H. Geller, J. Harris, M. Levine, A.H. Rosenfeld, *Annual Review of Energy* **12**, pp. 357–395 (1987).

"Energy for Buildings and Homes," R. Bevington, A.H. Rosenfeld, *Scientific American* **263** (3), pp. 77–86 (September 1990).

Getting American Back on the Energy-Efficiency Track: No-Regrets Policies for Slowing Climate Change, H.S. Geller, E. Hirst, E. Mills, A.H. Rosenfeld, M. Ross, American Council for an Energy-Efficient Economy, Washington, DC (1991).

"Realistic Mitigation Options for Global Warming," E.S. Rubin, R.N. Cooper, R.A. Frosch, T.H. Lee, G. Marland, A.H. Rosenfeld, D.D. Stine, *Science* **257**, pp. 148–49, 261–266 (July 1992).

"The New Downstream: Increased Efficiency and Renewables As Competitive Energy Resources," E. Mills, in *The Future of Energy Gases*, U.S. Geologic Survey (D. Howell, ed.), U.S. Geological Survey, Professional Paper 1570, U.S. Government Printing Office, pp. 849–867 (1993).

"Energy Efficiency, Market Failures, and Government Policy," M.D. Levine, E. Hirst, J.G. Koomey, J.E. McMahon, A.H. Sanstad, Lawrence Berkeley Laboratory Report No. 35376 and Oak Ridge National Laboratory Report No. 383 (1994).

Center for Building Science News, E. Mills (ed.), published quarterly, LBL PUB-731, available from the Center for Building Science, Lawrence Berkeley Laboratory, Berkeley, California.

Lighting

"Energy Efficiency and Performance of Solid-State Ballasts," R. Verderber, S. Selkowitz, S. Berman, *Lighting Design & Application*, pp. 23–28 (April 1979).

"Energy Savings with Solid-State Ballasts in a Veterans Administration Medical Center," R.R. Verderber, O.C. Morse, A.A. Arthur, F. Rubinstein, *IEEE Transactions on Industry Applications* **IA-18** (6), pp. 653–65 (November/December 1982).

"Thermal Performance Characteristics of Compact Fluorescent Fixtures," M.J. Siminovitch, F.M. Rubinstein, R.E. Whiteman, *Proceedings of the IEEE-IAS Annual Conference,* Seattle, WA (October 1990).

"Energy Efficiency Consequences of Scotopic Sensitivity," S.M. Berman, *Journal of the Illuminating Engineering Society* (Winter 1992).

Advanced Lighting Guidelines, C. Ely, T.M. Tolen, J.R. Benya, F. Rubinstein, and R. Verderbet, DOE/EE-0008 (1993).

Windows

"A Discussion of Heat Mirror Film: Performance, Production Processes and Cost Estimates," B. Levin, P. Schumacher, Lawrence Berkeley Laboratory Report No. 7812 (October 1977).

"Thermal Performance of Insulating Window Systems," S. Selkowitz, *ASHRAE Transactions* **85** (2), (June 1979).

"Window Performance and Building Energy Use: Some Technical Options for Increasing Energy Efficiency," S. Selkowitz, in *Energy Sources: Conservation and Renewables, AIP Conference Proceedings* No. 135, Washington, DC (April 1985).

"Savings from Energy Efficient Windows: Current and Future Savings from New Fenestration Technologies in the Residen-

tial Market," K. Frost, D. Arasteh, J. Eto, Lawrence Berkeley Laboratory Report No. 33956 (April 1993).

"Determining Thermal Performance of Window Systems," D. Arasteh, F. Beck, W.C. duPont, R.C. Mathis, *ASHRAE Journal* **36** (8), pp. 16–20 (August 1994).

"Advances in Window Technologies: 1973–1993," D. Arasteh, in *Advances in Solar Energy*, Vol. 9, The American Solar Energy Society, Boulder, CO (September 1994).

Appliance and Building Standards

"U.S. Residential Appliance Energy Efficiency: Present Status and Future Policy Directions," I. Turiel, D. Berman, P. Chan, T. Chan, J. Koomey, B. Lebot, M.D. Levine, J.E. McMahon, G. Rosenquist, S. Stoft, *Proceedings of the 1990 Summer Study on Energy Efficiency in Buildings,* American Council for an Energy-Efficient Economy, Washington, DC, pp. 1.213–1.234 (August 1990).

"Patterns of Energy Use in Buildings," in *Solar Heating Technologies: Fundamentals and Applications,* A.H. Rosenfeld, M.D. Levine, E. Mills, B. Hunn; B. Hunn (ed.), MIT Press (1994).

Design Tools and Other Software

"DOE-1: A New State-of-the-Art Computer Program for the Energy Utilization Analysis of Buildings," G.S. Leighton and H.D. Ross; A.H. Rosenfeld, F.C. Winkelmann, M. Lokmanhekim, LBL Report No. 7836 and *Proceedings of the International Symposium on the Use of Computers for Environmental Engineering Related to Buildings,* Banff, Canada (May 1978). (The current version is DOE 2.1E.)

CIRA—a PC-based tool for residential retrofit analysis, now marketed as EEDO by a private firm (Burt Hill Kosar Rittelmann and Associates, Butler, PA).

PEAR—a simplified PC-based tool, based on extensive DOE-2 simulations, readily usable by builders, architects, or lenders to provide reliable estimates of building energy consumption. See "Program for Energy Analysis of Residences: Pear 2.1 User's Manual," LBL Pub-610 (March 1987).

RADIANCE—a computer generated graphic simulation of lighting in indoor environments that is photometrically accurate and ultra-realistic. See "The Radiance Lighting Simulation and Rendering System," G. Ward, *Computer Graphics,* Association for Computing Machinery (July 1994).

SUPERLITE—a mainframe and microcomputer program that calculates daylight illuminance distributions for complex room and light source geometries with tested accuracy. See "The DOE-2 and SUPERLITE Daylighting Programs," S. Selkowitz, J.J. Kim, M. Navvab, F. Winkelmann, *Proceedings of the 7th National Passive Solar Conference,* International Solar Energy Society (June 1982).

Utility Accounting Program for Public Housing Authorities—a spreadsheet-based microcomputer program for tracking utility consumption and costs, designed especially for public housing authorities. See "The Utility Accounting Package: Version 1.0," K.M. Greely, E. Mills, R.L. Ritschard, S. Bartlett, prepared for the Innovative Technology and Special Projects Division, U.S. Department of Housing and Urban Development, LBL Pub-638 (1989).

WINDOW—a thermal analysis computer program that is the *de facto* standard used by U.S. window manufacturers to characterize product performance. See "WINDOW 4.0: Documentation of Calculation Procedures," E.U. Finlayson, D. K. Arasteh, C. Huizenga, M.D. Rubin, M.S. Reilly, LBL Report No. 33943 (July 1993).

COMIS (Conjunction of Multizone Infiltration Specialists)—An advanced computer model that simulates the air flow distribution in multizone buildings. This program was developed in an international effort by researchers from nine countries. See "The COMIS Infiltration Model—A Tool for Multizone Applications," H.A. Feustel, M.H. Sherman, *Proceedings of the XXI Symposium of the International Centre for Heat and Mass Transfer,* pp. 771–779, Dubrovnik, Yugoslavia, LBL Report No. 26550 (1989).

International

"Efficient Energy Use and Well-Being: The Swedish Example," L. Schipper and A. Lichtenberg, *Science*, **194**, pp. 1001–1013 (1976).

Proceedings of the ASEAN Conference on Energy Conservation in Buildings, K.H. Olson, W.W. Ching (eds.), U.S. Agency for International Development (1984).

Energy Efficiency and Human Activity: Past Trends, Future Prospects, L. Schipper and S. Meyers, Cambridge University Press (1992).

China Data Book, J.E. Sinton, M.D. Levine, F. Liu, W.B. Davis, J. Shenping, Z. Xing, J. Kejun, Z. Dadi (eds.), prepared by Lawrence Berkeley Laboratory and Energy Research Institute, State Planning Commission of China, LBL Report No. 32822 (1992).

Utility Planning

Least-Cost Utility Planning: A Handbook for Public Utility Commissioners, F. Krause, J. Eto, prepared for the NationAssociation of Regulatory Utility Commissioners, Washington DC (December 1988).

Primer on Gas Integrated Resource Planning, C. Goldman, G.A. Comnes, J. Busch, S. Wiel, prepared for the National Association of Regulatory Utility Commissioners, Washington DC (December 1993).

Indoor Environment

"Infiltration-Pressurization Correlation: Simplified Physical Modeling," M.H. Sherman, D.T. Grimsrud, *ASHRAE Transactions* **86** (2), pp. 778–807 (1980).

"Characterizing the Source of Radon Indoors," A.V. Nero and W.W. Nazaroff, *Radiation Protection Dosimetry* **7**, pp. 12–39 (1984).

"Distribution of Airborne Radon-222 Concentrations in U.S. Homes," A.V. Nero, M.B. Schwehr, W.W. Nazaroff, K.L. Revzan, *Science* **234**, pp. 992–997 (1986).

"Residential Duct System Leakage: Magnitude, Impacts, and Potential for Reduction," M.P. Modera, *ASHRAE Transactions,* **95** (2), pp. 561–569 (1989).

"Phase 1 of the California Healthy Building Study," W.J. Fisk, M.J. Mendell, J.M. Daisey, D. Faulkner, A.T. Hodgson, M. Nematollahi, J.M. Macher, *Indoor Air* **3**, pp. 246–254 (1993).

Global Climate

Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base, National Academy of Sciences, National Academy Press (A.H. Rosenfeld served as member of Mitigation Panel) (1992).

Federal Energy Efficiency

"The U.S. Department of Energy's In-House Energy Management Program: Meeting the Challenges of Federal Energy Management," S. Greenberg, E. Mills, D. Lockhart, D. Sartor, W. Lintner, *Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings* (August 1994).

"Deterrents to Energy Conservation in Public Housing," E. Mills, R.L. Ritschard, C.A. Goldman, *Energy Systems and Policy* **11** (3), pp. 169–183 (1987).

Industry Partners

AB Volvo
ADM Associates
Aerovironment
Air Quality Research
American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Andersen Corporation
Apple Computer
Asahi Glass
Association of Home Appliance Manufacturers
Bellcorp
Cardinal IG
Chevron
Conoco
Consolidated Edison
Cooper Lighting
Delray Lighting
Edison Price
Electric Power Research Institute
ERG International
Exxon USA
Finite Technologies
Fusion Lighting
Gable Dodd Associates
Gas Research Institute
General Electric
Honeywell
Indy Lighting
ITEM Systems
Libbey Owens Ford
Lightolier
Lithonia
Lumatech
Microflect
Mitor Industries
National Fenestration Rating Council
Northern States Power
Osram
Owens-Corning Fiberglas
Philips Lighting
Pacific Gas and Electric
Partnership for Resource Conservation
Peerless Lighting
Pella Windows
Prescolite
Reggiani
Rolscreen
San Diego Gas and Electric
Shell Oil
Southern California Edison
Southern Company Services
Southwall Technologies
Staff Lighting
Zumtobel
3M Corporation

Some of Our Partners...

The Lawrence Berkeley Laboratory has repeatedly been on the forefront of demonstrating that energy efficiency can not only compete effectively with energy production, but can offer significant advantages in terms of environmental and economic impacts and competitiveness. . . LBL has earned the support and trust of the entire energy efficiency industry and deserves the opportunity to continue this work in the critically important role of getting our national energy strategy working.

Peter F. Gerhardinger
Manager–New Products Technology, Libbey Owens Ford Co.

We have been working with LBL's Lighting Systems Group in an effort to adapt their technology for commercialization. . . We can now see a clear role for these technologies in our products. The implementation of this technology should greatly enhance an already attractive market. . . As taxpayers we are pleased to see us getting so much bang for our buck. The LBL group will be responsible for a great deal of energy savings. They should please everyone but OPEC.

Bruce Pelton
Vice President, Lumatech Corporation

With the information I recently received from LBL concerning the performance of compact fluorescent lamps with attached reflectors, we can now improve the quality of our product with minimum investment while at the same time providing the end user with greater light output at even higher product efficiency. . . LBL's work not only benefits the original equipment manufacturer, providing insight on how to produce a more efficient product, but in the long term benefits the consumer and society with reduced emissions and reduced energy bills. Clearly the output of LBL benefits society, manufacturers and end users.

Steve Johnson
President, Mitor Industries Inc.

Investment by the Department of Energy allowed Southwall Technologies, working closely with LBL, to introduce in 1981 the first insulating glass containing a heat reflecting, low emissivity coating. . . [The product] served as the catalyst in creating a high performance window industry.

Southwall Technologies, Press Release

We committed well over a year ago to early in-depth data gathering, analysis, cooperation and communication with DOE and LBL, and we're very pleased with the results of that effort.

Charles Samuels
Association of Home Appliance Manufacturers, Government Relations Counsel
U.S. Department of Energy Public Hearings on Appliance Standards

Refrigerator manufacturers have been working closely with LBL for over a year now to evaluate design options and develop cost data for this appliance standards rulemaking. We very much appreciate the cooperation and professionalism that LBL has shown throughout this process.

Terry Thiele
Senior Counsel for Government Relations, GE Appliances
U.S. Department of Energy Public Hearings on Appliance Standards

Lawrence Berkeley Laboratory is one of the founders of so-called end-use-based economic engineering analysis and utility least cost planning. These two revolutionary advancements in energy analysis and planning are considered key to creating a burgeoning, lucrative global market in super-efficient environmentally superior products and services. . . LBL is one of the most respected energy R&D laboratories in the world. . . which has catalyzed development of super-efficient technologies and building design software.

Senator John Glenn
Senator Herb Kohl

The long-standing LBL-EPRI relationship has greatly improved the forecasting abilities of the electric power industry. With the resulting end-use models and associated databases, utilities can more easily integrate the impacts of demand-side management programs, efficiency standards, and new technologies into their long-term forecasts. This improves the quality of a variety of utility functions.

Phil Hanser
Manager, Demand-Side Management Program
Electric Power Research Institute

World-renowned Lawrence Berkeley Laboratory has performed critical work leading to the development of important new building technologies like electronic ballasts for fluorescent lighting and low-emissivity windows. These two products alone have created important new global markets for U.S. companies and saved Americans millions of dollars.

Ed Smeloff
Director, Sacramento Municipal Utility District

The Lawrence Berkeley Laboratory has been a major motivating force for energy efficiency in California for over 15 years. As early as 1978, the intellectual leadership of LBL staff highlighted that efficient appliances could pay for themselves by reducing consumer utility bills, and also eliminate the need for a large nuclear plant in Southern California. LBL pioneered the concept of "conservation supply curves" that has facilitated the economic comparison of efficiency with conventional energy supplies, and resulted in the California Energy Commission establishing conservation as the state's preferred source of new energy supply. They have also consistently shown the link between conservation with environmental benefits, which has led to efficiency being the foundation of California's efforts to meet our environmental goals. . . LBL also has advised the legislature on regulatory and policy improvements that should be made to help California achieve its energy and environmental goals which resulted in the introduction of 20 new bills in the last legislative session. The Commission is implementing efficiency programs that can trace their roots to LBL's long-standing efforts to ensure that advances in science also improved California's economy and environment.

Charles R. Imbrecht
Chairman, California Energy Commission

Public Sector or Non-Governmental Partners

Agency for International Development
Alliance to Save Energy
American Council for an Energy-Efficient Economy
Audubon Society
Bonneville Power Administration
California Air Resources Board
California Department of Health Services
California Energy Commission
California Institute for Energy Efficiency
Central European University
Cigarette and Tobacco Surtax Fund of The State of California
Danish Energy Agency
Environmental Defense Fund
European Association for the Conservation of Energy
Federal Aviation Administration
General Services Administration
Green Buildings Council
International Association for Energy-Efficient Lighting
International Energy Agency
Kuwait Institute of Scientific Research
Los Angeles Department of Water and Power
Mexican National Commission on Energy
National Association of Regulatory Utility Commissioners
National Heart, Lung and Blood Institute
National Institute of Environmental Health Science
Natural Resources Defense Council
New York State Energy Research and Development Authority
Organization for Economic Cooperation and Development
Pew Charitable Trust
Rockefeller Family and Associates
Rocky Mountain Institute
Russian Lighting Research Institute
Sacramento Municipal Utility District
Sierra Club
Stockholm Environment Institute
Swedish National Board for Industrial and Technical Development
Texas Governor's Energy Office
The Energy Foundation
U.S. Consumer Product Safety Commission
U.S. Department of Energy
U.S. Department of Housing and Urban Development
U.S. Environmental Protection Agency
U.S. Food and Drug Administration
U.S. Navy
University of California
World Energy Council

Listed are companies or organizations that have funded or otherwise participated in LBL research projects or directly utilized the research results. Further information available on request.

About the Center for Building Science

Addressing significant energy-related issues, the Lawrence Berkeley Laboratory's Center for Building Science has become an international leader in developing and commercializing energy-efficient technologies and analytical techniques, and documenting ways of improving the energy efficiency and indoor environment of residential, commercial, and industrial buildings.

The Center is the home of three programs—Building Technologies, Energy Analysis, and Indoor Environment. It serves as a national and international source of information for energy-efficient technology, provides technical support to energy and environmental policymakers, supports and creates institutions and demonstration programs, provides a training ground for students in the energy field, and facilitates transfer of technology and information to the private sector.

Researchers at the Center recognize that despite significant, steady progress since the energy crises of the 1970s, a large potential for energy savings remains to be realized. The Center's interdisciplinary staff of 250 studies a wide spectrum of environmental, economic, and technical aspects of energy-efficiency activities, each helping to document that energy efficiency is a new and highly cost-effective energy resource.

Colophon: *This report prepared by Evan Mills and edited by Allan Chen and Jeff Kahn. Original graphics and interior design by Sam Webster. Cover design by Flavio Robles.*

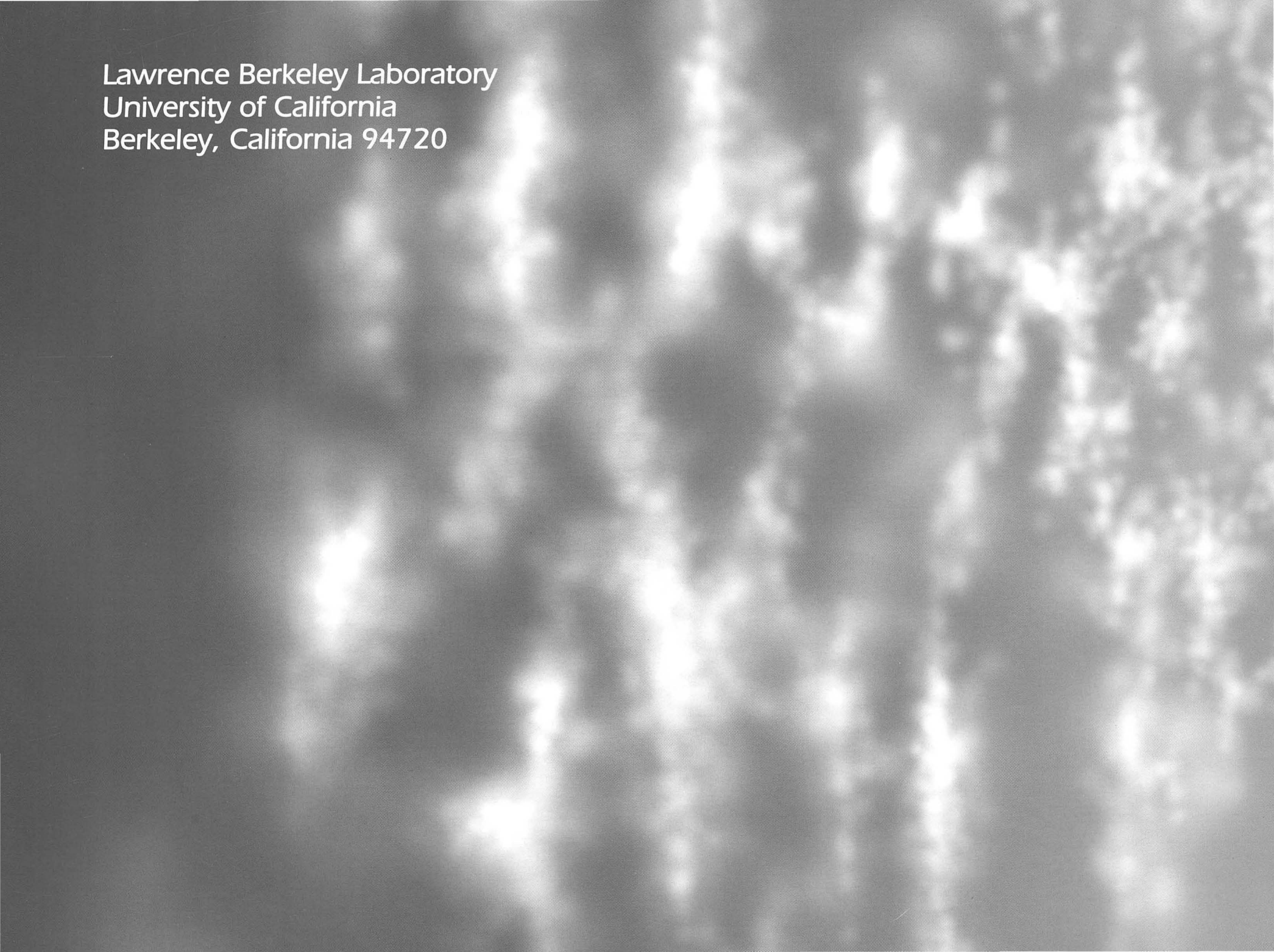
This work was funded by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technologies of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. Neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California and shall not be used for advertising or product endorsement purposes.

Lawrence Berkeley Laboratory is an equal opportunity employer.

PUB-758



Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720