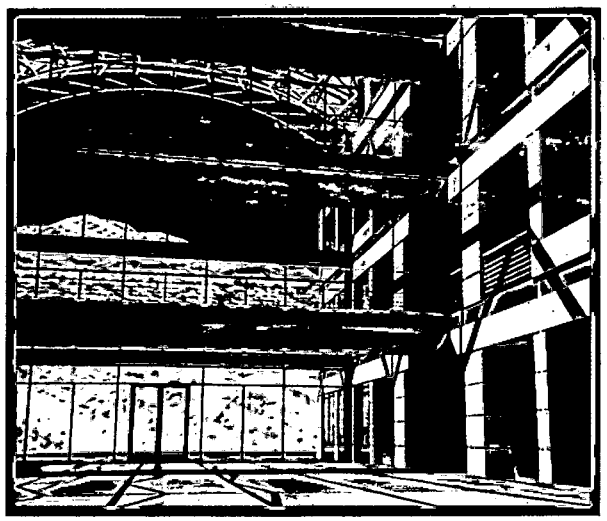
Energy & Environment Division
Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Building Technologies Program

1992 Annual Report



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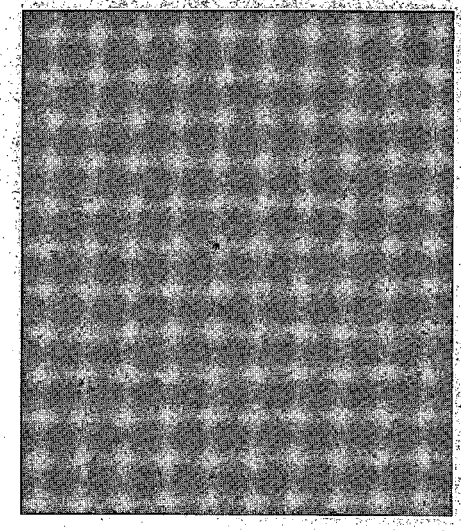
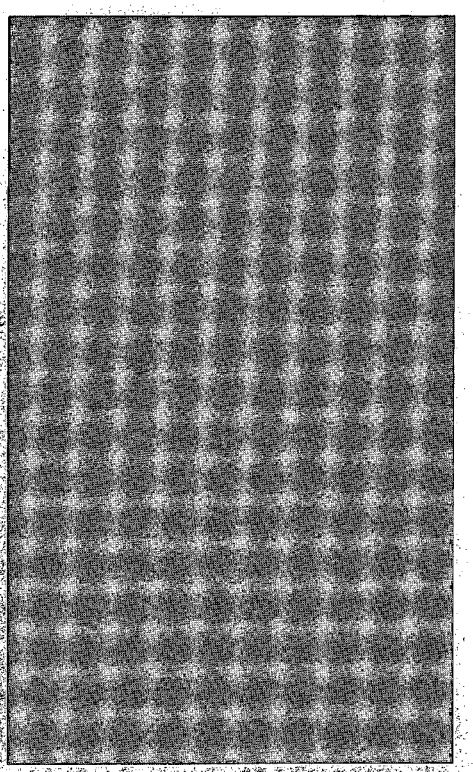


Building Technologies Program 1992 Annual Report

Stephen E. Selkowitz, Program Leader



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Introduction

The objective of the Building Technologies program is to assist the U.S. building industry in achieving substantial reductions in building-sector energy use while improving the comfort, amenity, health, and productivity in the building sector. We focus our efforts on two major building systems—windows and lighting—and the simulation tools needed by researchers and designers to integrate the full range of energy efficiency solutions into achievable, cost-effective design solutions for new and existing buildings.

More than 30% of all energy use in buildings is attributable to two sources: windows and lighting. Together they account for annual consumer energy expenditures of more than $50 billion. Each affects not only energy use by other major building systems, but also comfort and productivity—factors that influence building economics far more than does direct energy consumption alone. Windows play a unique role in the building envelope, physically separating the conditioned space from the world outside without sacrificing vital visual contact. Throughout every space in a building, lighting systems facilitate a variety of tasks associated with a wide range of visual requirements while defining the luminous qualities of the indoor environment. Window and lighting systems are thus essential components of any comprehensive building science program.

Building simulation models are key elements of any effort to improve the energy efficiency of the building sector. They are used directly by researchers (to better understand the relative benefits of technology options) and by government (to develop effective codes and standards). Simulation models form the technical basis for design tools that permit design professionals to fully evaluate the impact of design alternatives and ultimately to optimize their designs long before the first concrete is poured.

Despite important achievements in reducing building energy consumption over the past decade, significant additional savings are still possible. These will come from two complementary strategies: 1) developing advanced technologies that increase the savings potential for each building application; and 2) developing advanced simulation and design tools so that building professionals can effectively apply existing technologies and extend the market penetration of these technologies.

The **Windows and Daylighting Group** focuses on the technical aspects of understanding and improving the energy-related performance of windows. If the flow of heat and light through windows and skylights can be properly filtered and controlled, these building elements can outperform any insulated wall or roof component and thereby provide net energy benefits to the building. The group's investigations are designed to develop accurate systems for predicting net fenestration performance in residential and commercial buildings. Simulation studies, field measurements in a mobile field test facility, and building monitoring studies help us to understand the complex tradeoffs encountered in fenestration performance. The research program is

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conducted with the participation and support of industry, utilities, universities, design professionals, and government. The group's three major project areas are optical materials, fenestration performance, and building applications and design tools.

In our studies of optical materials and advanced concepts, we develop and characterize thin-film coatings and other new optical materials that control radiant and thermal flows through glazings. Innovative concepts for large-area envelope enclosures are studied. The group helped accelerate the development and market introduction of windows that incorporate high-transmittance, low-emittance (low-E) coatings for R3-R5 windows. If sales follow current trends, by the year 2000 these coatings will save consumers more than $3 billion annually in heating bills alone.

Our research on window performance aims to develop new analytical models and experimental procedures to predict the thermal and solar-optical properties of the complex assemblies of glazing materials and shading devices that compose complete fenestration systems. This activity directly supports the efforts of the National Fenestration Rating Council to develop an accurate and fair system for rating and labeling the energy performance of windows. Thermal performance models are being validated using the Mobile Window Thermal Test Facility (MoWiTT), now collecting data at a field test site in Reno, Nevada. This unique facility combines the accuracy and control of laboratory testing with the realism and complexity of dynamic climatic effects. LBL daylighting studies employ a 24-foot-diameter sky simulator (for testing scale models under carefully controlled conditions) and new experimental facilities for measuring the photometric and radiometric properties of complex fenestration systems.

Studies in the building applications and design tools area help us to understand the complex tradeoffs in fenestration performance as a function of building type and climate. In nonresidential buildings, major reductions in electric energy use and peak electric demand can be achieved if the tradeoffs between daylight savings and solar-induced cooling loads are understood. We are developing concepts for an Advanced Envelope Design Tool using new imaging techniques and expert systems.

The **Lighting Systems Group** focuses its research on three areas: advanced light sources, building applications, and impacts of lighting technologies on performance and health.

Our research on advanced light sources is concerned primarily with developing new technical concepts for efficiently converting electrical energy into visible light. The primary effort is devoted to the development of electrodeless lamps that operate at megahertz frequencies at the allowed ISM (industrial, scientific, and medical) frequencies of 13.56, 27 and 40 MHz. We are investigating replacements for both fluorescent and high-intensity discharge (HID) lamps. These lamps promise both more efficient conversion of electrical energy into visible light, and considerably longer lamp life.

The building applications research concentrates on technical approaches leading to major improvements in fixture efficiency and effective use of lighting controls, as well as how these factors interact with a building's heating, ventilation, and air-conditioning (HVAC) system. We have developed several innovative, highly cost-effective approaches for improving fixture efficiency about 15% that have become part of the present market. In addition, we are studying visual quality issues, primarily obtaining basic information on lighting and visual performance in order to provide an analytic basis for lighting recommendations.

Our studies in the impacts area extend research in electric lighting to a broader range of human activities. In specially designed experimental rooms with controlled lighting conditions, human responses are measured objectively by sensitive instrumentation. We have obtained data on the effects of lamp spectral composition on visual function and on brightness perception, and are studying how these results can affect improvements in the energy efficiency of lighting design. Additional studies on glare and flicker as they relate to performance, especially in the automated workplace, are ongoing.

The Lighting Group's successes include advancing the development of high-frequency solid-state ballasts for fluorescent lamps, the invention of a series of methods for efficiently coupling megahertz frequencies into both electrodeless fluorescent and HID lamps, and a number of technical improvements to fluorescent fixtures that have become the industry standard. A two-year test of solid-state ballasts in a large office building showed an electricity savings of 40%. Scaled to the entire country, this represents an annual potential savings of $5 billion. The energy-efficient megahertz frequency technology has the potential to obtain major reductions in lighting energy use without compromising light levels, while providing considerably longer lamp life.

The primary contribution of the **Simulation Research Group** has been the development of DOE-2, a widely-used whole-building analysis program that calculates energy use and cost, given information about a building's climate, construction, operation, HVAC and lighting equipment, and utility rate schedule. DOE-2 is used by consulting engineers for design of energy-efficient buildings, by researchers for impact analysis of new heating, cooling and lighting technologies, and by state and federal agencies for development of energy-efficiency standards (such as the new DOE/ASHRAE Standard 90.1 for commercial buildings). In collaboration with the Electric Power Research Institute, we have recently begun work to make DOE-2 easier to use and to enhance its calculational capabilities.

This group also carries out fundamental research into new techniques for simulating complex physical systems. The main result of this effort is an advanced simulation program, SPARK (Simulation Problem Analysis and Research Kernel), that allows users to quickly construct calculation models that are much more detailed than those in programs like DOE-2. SPARK users choose calculation components from a library and graphically link them together into networks that describe the building of interest. SPARK will allow researchers to explore the dynamic behavior of complex systems with an ease and accuracy unachievable with conventional software.

Windows & Daylighting

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Approximately 20% of the energy consumed annually in the United States is used for space conditioning of residential and commercial buildings. About 25% of this amount is required to offset heat loss and gain through windows. In other words, 5% of U.S. energy consumption—the equivalent of 1.7 million barrels of oil per day—is related to the performance of windows. Fenestration performance also directly affects peak electrical demand in buildings; sizing of the heating, ventilating, and air-conditioning (HVAC) system; thermal and visual comfort of building occupants; and human health and productivity.

With more intelligent use of existing technology and with development of new high-performance window materials, windows can be converted from energy liabilities to energy benefits. The aim of the Windows and Daylighting Group is to develop tools and technologies necessary to accomplish this goal. We develop advanced technologies and create procedures to predict and improve the thermal and daylighting performance of windows and skylights. The group's work helps generate guidelines for design and retrofit strategies in residential and commercial buildings and contributes to development of advanced computer-based tools for building design. Although our primary focus is improving energy efficiency, we seek solutions that also improve comfort, health, and amenity within buildings, and minimize undesired environmental impacts on a local, national, and international scale.

Our program's strength lies in its breadth and depth: we examine energy-related aspects of windows at the atomic and molecular level in our materials science studies, and at the other extreme we perform field tests and *in situ* experiments in large buildings. We have developed, validated, and now use a unique, powerful set of computational tools and experimental facilities. Our scientists, engineers, and architects collaborate with researchers in industry, academia, utilities, and government to accomplish our objectives.

To be useful, the technical data developed by our program must be communicated to design professionals, to industry, and to others in the public and private realms. We publish our results and participate in industrial, professional, and scientific meetings and societies (national and international) to ensure that our research results are widely disseminated. Much of our R&D activity is undertaken in close collaboration with the organizations that will ultimately utilize the results of our work to advance energy efficiency within the building community.

Our overall strategy is to develop the knowledge base needed to maximize the energy efficiency of existing technology and to assist industry in the development of the next generation of energy-efficient window systems. To carry out this effort, we have organized our research into three major areas:

- Advanced materials and concepts
  - *optical and thermal materials*
  - *advanced systems and concepts*
- Fenestration performance
  - *window rating systems*
  - *thermal analysis*
  - *daylighting analysis*
  - *field measurement of performance*
- Building applications and design tools
  - *nonresidential buildings*
  - *residential buildings*
  - *advanced design tools*

Advanced Materials

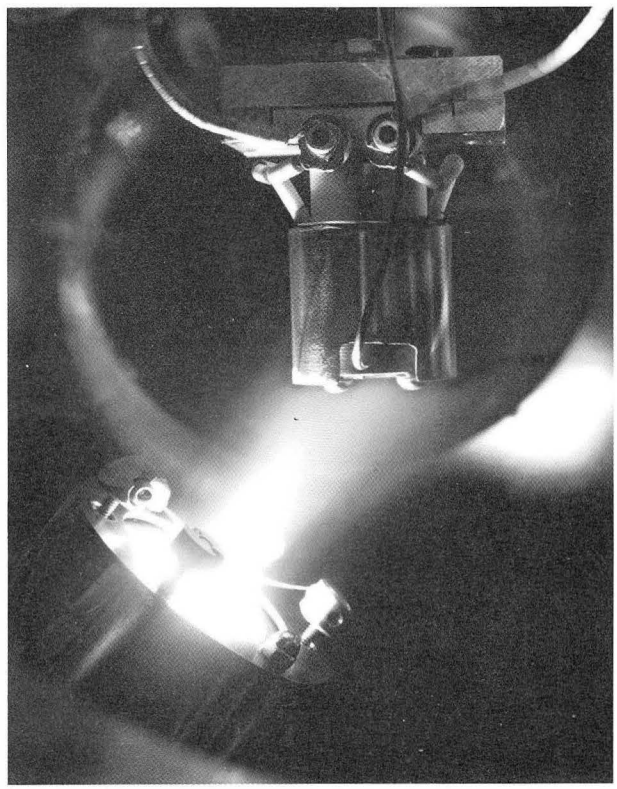
Significant reductions in energy consumption by buildings will result from the development and introduction of new high-performance glazing materials. Since the inception of our program, we have worked to identify, characterize, and develop promising new optical materials to assist industry in developing the next generation of advanced fenestration systems. We provide scientific coordination for DOE-funded research projects at universities, private-sector firms, and other national laboratories. We also work to transfer our research results to the private sector.

In 1976, development of low-emittance (low-E) coatings was a major objective of our program, and our DOE-supported research subsequently accelerated market introduction of high-performance low-E window systems. Incorporating low-E coatings into conventional double-glazed windows produces a lighter, more compact unit showing better thermal performance than that of triple-glazed windows. First introduced commercially in 1982, low-E coatings are used today in more than 30% of all residential windows.

Our work on Superwindows incorporates low-E technology and gas fills, and has recently led to several commercially available products. These highly insulating glazings have such low heat transfer rates that they can outperform the best insulated walls in winter on any orientation in virtually any U.S. climate. Modified low-E coatings which transmit daylight but reject near-infrared radiation (i.e., spectrally selective coatings) have been developed for cooling-dominated climates. We are supporting projects to develop improved spectrally selective coatings and to help specifiers utilize these technologies more effectively. We are accelerating our efforts to develop "smart windows"—specifically, electrochromic materials and devices possessing optical properties that respond to changing environmental conditions. These devices, and other optical materials that can control incident daylight, will provide window systems with comprehensive energy management capabilities that will allow them to deliver net energy benefits to buildings in virtually all climates.

Figure 1.

Ion-assisted high-temperature deposition system for deposition of highly crystallized metalic compounds. (CBB 926-4644)



Durable Solar-Control and Low-Emittance Coatings

The objective of this project is to develop and accelerate the use of spectrally selective coatings for control of daylight and solar heat gain. Spectrally selective glazings preferentially transmit visible light while rejecting the near infrared component of sunlight. Cool glazings based on silver combine a high visible transmittance with high infrared reflectance to minimize cooling load. Some metallic compounds are more durable than silver and in some cases have superior optical properties. These coatings could be used in unprotected glazing applications for which silver-based coatings would be unsuitable. A new system for deposition of these materials was completed, and features a very uniform high-temperature stage, a versatile gaseous ion source, several metal atom sources, and good beam diagnostics (Fig. 1). We deposited several types of oxides and nitrides, using high substrate temperatures and ion-assisted techniques to enhance their crystallinity and electronic properties. Tungsten bronze films were made with optical properties nearly equal to those of single crystals. Continuing research in 1993 will attempt to produce coatings with these excellent optical properties at lower temperatures, thus simplifying the production process.

Most specifiers are unaware of the performance potentials of "cool glazings." A workshop on spectrally selective glazings, co-sponsored by glazing manufacturers and public utilities, was held in San Francisco. Glazing manufacturers were informed of the new utility DSM programs that could increase

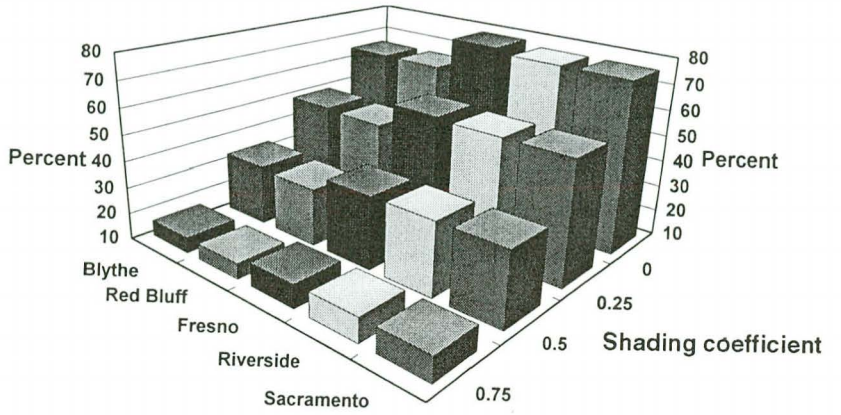


Figure 2.

Reduction in window peak electric demand for cool glazings over a range of shading coefficients and climates.

market acceptance of their products, and utilities learned about emerging glazing technologies to assist them in designing new incentive programs. Almost all existing residences in California use clear glazing, which admits high levels of solar gain and thus contributes to cooling loads. With co-sponsorship from CIEE, we simulated the energy performance of typical residences over a range of glazing characteristics and climates. Figure 2 shows that the peak demand can be significantly reduced through the use of spectrally selective glazings over a range of California climates.

Low-Conductance Glazings and "Superwindows"

Many window manufacturers are offering glazing systems with low-emissivity coatings and low-conductivity gas filling. These windows have center-of-glass R-values between 3 and 4 hr-ft^2-F/Btu. Since 1985, we have been working to develop the technology base for the next generation of highly insulating windows. Such superwindows will have total window R-values between 6 and 10 hr-ft^2-F/Btu and, even in northern U.S. climates, will be able to transmit more useful solar gains (from any orientation) than they lose in conduction. Superwindows will thus require less total heating energy than insulated walls over a complete heating season.

In 1988 we began a project with several major window manufacturers and the Bonneville Power Administration (BPA) to design and manufacture prototype first-generation superwindows for three BPA super energy-efficient demonstration homes in Montana. These windows were designed to build on existing manufacturing processes and to utilize glazings with center-of-glass R-values between 6 and 10 hr-ft^2-F/Btu. Beginning in 1990, several national manufacturers began to offer products with such superglazings.

During the winters of 1989-1990 and 1990-1991, these three BPA homes were monitored to assess their field performance. Results showed that these glazing systems can perform as well as an insulated wall, although the total window, including the sash and frame, does not perform as well. These results reinforced the need to concentrate on improving the thermal performance of the sash and frame.

In 1992, we focused our attention on working with the window industry to develop higher performance edge and frame systems for both superwindows and conventional windows. Our Infrared Thermography Laboratory, established in 1990, was used to test prototype windows from more than a dozen manufacturers. Test results were analyzed by LBL staff and were shared with each cooperating manufacturer (Fig. 3). Our superwindow research efforts focused on developing design concepts for high-performance vinyl

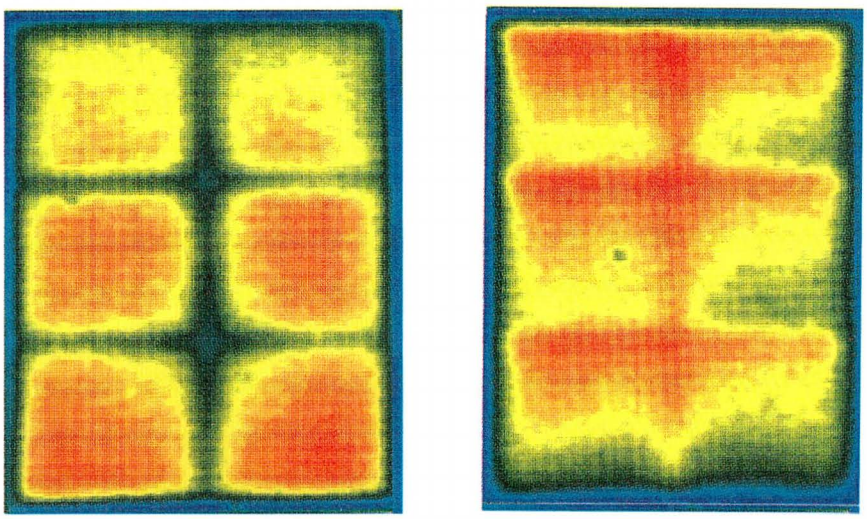


Figure 3.

The thermal effects of architectural muntin bars (thin suspended interior dividers) on glazing performance were analyzed using infrared thermography. In these infrared images of the warm side of two windows (with identical muntin bar patterns exposed to simulated winter conditions), blue/green areas indicate colder temperatures and are thus poor insulators. For gap widths of 0.25" or less (left image), the muntin bars create a thermal bridge. For gaps of 0.50" or greater (right image), thermal performance was not compromised.

framed profiles. We also used our IR thermography facility to collaborate with manufacturers of typical aluminum, wood, and vinyl profiles who were interested in making design changes in order to improve the thermal performance of their frames. In some cases, we ended up learning that solutions proposed by the individual manufacturers did not perform as well as initially expected. Improved frames, edges, and window/wall interfaces will be the focus of our research efforts for the next few years.

Advanced Insulation Systems

In 1990, as a spinoff from our superwindow research, we invented a new design for an energy-efficient, non-CFC opaque insulation. With support from the California Institute for Energy Efficiency, the U.S. DOE, and the EPA, we showed that the use of low-emissivity surfaces and multiple, low-conductivity, gas-filled cavities can result in a highly insulating panel that can be fabricated using existing materials and technologies. We call this new insulating material gas-filled panels (GFPs). Applications for GFPs are widespread and focus primarily on replacing CFC blown foams in refrigerator/freezer appliances and in building components (Fig. 4).

GFPs are not a homogeneous insulating material such as fiberglass or foam, but rather an assembly of two specialized components. The first component is a barrier envelope that contains a gas, or gas mixture, at atmospheric pressure. Placed inside the envelope is the second component—a baffle consisting of multiple, low-emissivity coated layers. The baffle effectively eliminates radiative and convective heat transfer, leaving primarily conductive heat transfer through the gas and baffle. GFPs can be constructed with mechanical properties ranging from flexible but self-supporting to stiff and supportive.

The thermal performance of GFPs has been independently tested at Oak Ridge National Laboratory (ORNL), and predicted thermal performance values were achieved. Measurements yielded R-values per unit thickness of 36 m-K/W (5.2 hr-ft^2-F/Btu-in) for air-filled panels, 49.3 m-K/W (7.1 hr-ft^2-F/Btu-in) for argon-filled panels, and 86.8 m-K/W (12.5 hr-ft^2-F/Btu-in) for krypton-filled panels. Thus, air-filled panels perform as well as styrene foam, and argon-filled panels perform as well as CFC blown foams—a performance level twice that of fiberglass. Krypton-filled panels offer performance levels much higher than any currently commercially available insulation.

Development and applications oriented testing of GFP prototypes continued during 1992. We continued basic collaborative research efforts with GFP raw materials suppliers in order to produce more effective gas-barrier and baffle materials. GFP technology was licensed by a manufacturer of medical specimen shipping containers and is expected to form the basis for a new generation of medical specimen shipping containers. In order to optimize the use of GFPs in refrigerator applications, we examined the effects of thermal bridging around advanced insulations in refrigerators constructed using today's typical steel shell and found these losses to be very significant. We therefore began to investigate the use of GFPs with polymer-based refrigerator shells. Research efforts during 1993 will focus on developing prototypes of polymer shells incorporating GFPs as an insulating material.

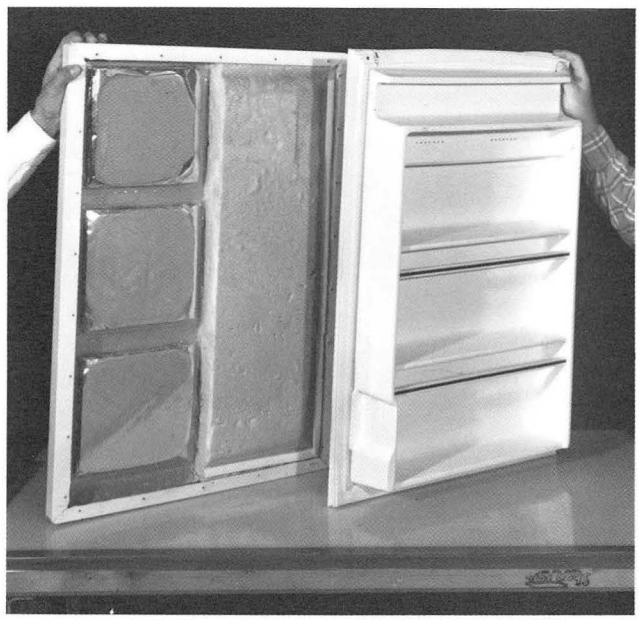


Figure 4.

A refrigerator door originally insulated with a CFC blown foam insulation has had half of the insulation removed and replaced with three gas-filled panels (left side); these panels are thinner yet outperform the foam insulation. (CBB 918-6782)

Optical Switching Devices

Chromogenic glazings can dynamically control the flow of visible and thermal radiation through windows in buildings, automobiles and aircraft. Electrochromic materials, among other chromogenic technologies such as liquid crystals and photochromics, provide the most versatile and appropriate technology for these applications. Electrochromic glazings could achieve 10-80% visible light transmission with moderately fast switching times and low d.c. power consumption. Smart control systems can be used with electrochromics to maintain specified daylighting levels and reduce building energy consumption.

We completed a study on the performance of generic electrochromic windows in commercial buildings for Southern California Edison. We found that electrochromic windows can out-

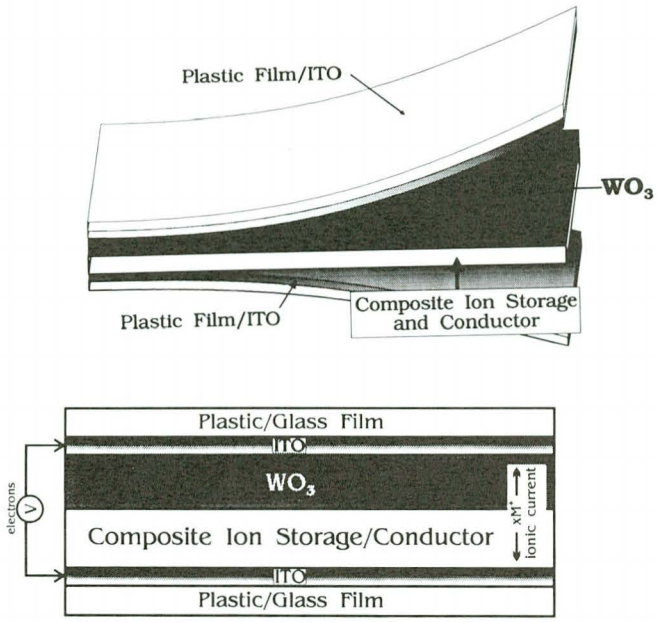


Figure 5.

Schematic of solid-state electrochromic device constructed using a composite ion storage/ ion conductor and flexible plastic or glass substrates. (XBL 921-222)

perform other types of advanced glazing in both moderate and hot climates. Savings include total lighting, cooling and peak utility loads. Other benefits include reduced HVAC system size and greater thermal and visual comfort. Energy benefits and related savings can produce paybacks as short as three years. We also refined the descriptions of some real electrochromic materials and installed their performance parameters into the glazing library of DOE 2.1E, which is equipped with a more sophisticated window model. Next year, we will use this program to estimate energy savings using the current generation of prototype electrochromic devices.

The major components in an electrochromic device are the electrochromic and the ion-storage electrodes, separated by the ion conductor. All these layers must be electrochemically compatible, chemically stable in contact with each other, and be able to store and transport charge or ions reversibly for many cycles over long periods of time. We have developed sputtering techniques to reproducibly coat glass with electrochromic nickel, tungsten and niobium oxides. We have transferred this technology to Southwall Technologies for the coating of flexible polyester substrates. We also have a collaboration with Dow Chemical to develop and characterize devices which combine our electrodes with their polymer electrolyte. During 1992, we constructed electrochromic devices using nickel oxide, tungsten oxide, niobium oxide and polymer ion conductors. One of our best devices (nickel oxide:cobalt/ lithium polymer/tungsten oxide) showed a change in visible transmission of greater than 50%. The stability of this device has been increased by improvements in the lithium polymer ion conductor and device fabrication techniques.

We have made further significant developments in polymer ion storage materials in collaboration with LBL's Battery Group. We were granted a patent for ten families of organodisulfide polymers for electrochromic devices. We established materials exchange agreements for these polymers with several companies which could lead to licensing agreements. We have another patent pending on two groups of mercaptans and organthiols as storage materials. These materials have unusual electrical and ionic properties that allow a single composite polymer layer to serve as both the ion storage electrode and the ion conductor. Devices based on these new composite materials would have a compact design and lower cost. Figure 5 shows the structure of a typical device. Tungsten oxide devices incorporating these composite polymers had a change in visible transmission of up to 45%. Figure 6 illustrates the switch from a light grey with the application of 1.2V.

Our research in FY93 is directed at improvement of the electrochromic glazing device stability and scale-up of the device size in collaboration with industry partners. We will continue to improve polymer ion storage andconductor layers. We will refine glazing fabrication techniques for laminated

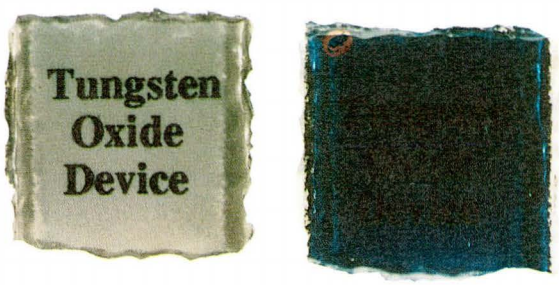


Figure 6.

The words printed behind it are clearly visible when an electrochromic device is switched to a high-transmission state. It becomes opaque when ions move into the electrochromic layer and react with tungsten oxide. (CBB 916-4871C)

devices and transfer sputter-deposited coating technology to processors of glass and polyester. Energy modeling will continue using the WINDOW 4.0 window simulation program and DOE 2.1E building energy simulation program for switchable windows in a variety of climates and building designs.

Automobile Glazings

Much of our group's expertise in the technology and performance of glazings for buildings is directly applicable to automobile windows. Reduction of the solar load would reduce the need for CFC refrigerants, save fuel, improve passenger comfort and safety, and prevent the degradation of materials. The range of electric vehicles could be extended by direct reduction of cooling load on the battery-powered air conditioner. We investigated applications of durable selective coatings, electrochromic coatings, and angle-selective coatings to automobile windows, as well as compact body insulation for electric vehicles in cold climates. In prior studies we developed simulation models to predict internal temperatures and heating/cooling loads. Infrared thermography was used to observe the reduction in surface temperatures when using high-performance coatings. The results were in good agreement with simulations we performed in collaboration with Airco Coating Technology.

Fenestration Performance

Effective use of fenestration systems to achieve a more energy-efficient building stock not only requires improved window systems and components, but also the intelligent inclusion of energy considerations into the matching between fenestration systems and architectural needs. To achieve this, it is necessary to have the means to determine fenestration energy performance under a wide variety of conditions. Research in fenestration performance thus forms the bridge between new technology and its effective application. Activities in this area are intended to characterize the performance of fenestration components and complete systems over the entire range of operating conditions in any climate or building type. The research develops and refines experimental techniques and analytical models for accurately determining heat-transfer and solar-optical properties of fenestration components and systems, and validates these models in field test facilities and in occupied buildings. Many of the new algorithms and data sets are designed to be incorporated into hour-by-hour building energy simulation programs such as DOE 2.1, while others are directly applicable to window standard and labeling activities. These data not only improve the accuracy of our predictions, but also allow us to predict the performance of new fenestration systems and novel architectural designs. The primary focus of our performance research tests has been to provide performance characteristics procedures and related technical support to the National Fenestration Rating Council (NFRC) to assist it in development of window energy rating systems.

Window Rating and Labeling Systems

The development of many new energy-efficient window systems in the last several years has created the need for an accurate, fair, and cost-effective means to evaluate the thermal performance of all fenestration products. Such a system must meet the demands of manufacturers, architects/engineers, builders, state regulators, utility incentive programs, and consumers. The National Fenestration Rating Council (NFRC) was formed in 1989 by representatives of all these groups with this objective in mind. We have taken a lead role in working with the NFRC's Technical Committee to develop and document procedures to rate window properties and annual energy effects. A U-value procedure, finalized in 1991, is based on the simulation procedure in the WINDOW program and the Canadian program, FRAME. During 1992, we worked with the NFRC to make this procedure more accurate and less costly to implement. We also worked with test and simulation laboratories and the NFRC to provide technical validation of the procedure. Draft solar heat gain and optical properties procedures are based on the use of WINDOW 4.0. To aid NFRC in the development of an Annual Energy Index, we developed a draft version of a PC program, RESFEN, which calculates seasonal and annual energy impacts of fenestration products in typical residences throughout the United States. We will continue to expand our technical involvement with other NFRC related issues relating to the development of these and other NFRC procedures (i.e., infiltration, durability, and condensation resistance).

Thermal Analysis

The growing use of advanced optical coatings, gas fills, and insulating edges and frames has increased the number of window configurations available. Beginning in 1986, we released the WINDOW program to aid in the evaluation of new product options and to serve as a standard for calculating window heat transfer properties. This tool has been updated several times with the most recent major update released as WINDOW 4.0 in 1992. The program now incorporates the National Fenestration Rating Council's standard procedure for rating the U-values of fenestration products. In addition, it also includes the ability to perform a multi-band spectral analysis, thereby increasing the accuracy of multi-layer solar heat gain and optical property calculations. A model to estimate the solar heat

gain effects of frames is included with the program. The glazing layer library was updated and expanded significantly. Finally, the program's output can be utilized by a draft version of the DOE 2.1E building energy analysis program. More than 2,000 copies of WINDOW 4.0 were provided free of charge to window manufacturers and the building industry.

Optical Performance

Characterization of the optical properties of window materials and systems provides feedback for materials development, input data for energy performance calculations, and product evaluations for rating and labeling activities. Most of this work is now coordinated through the Optical Properties Subcommittee of the NFRC. Our first goal was to complete procedures for the measurement of the solar optical and thermal infrared properties of clear, coated, laminated, and some types of diffuse materials. Two draft procedures have been written, and they are now being considered by the NFRC as well as the ASTM. One major missing piece of these procedures is an accurate method for determining angle-dependent properties. We are developing experimental techniques for performing these measurements (Fig. 7) and using the results to provide extrapolations from easily measured normal-incidence properties. A procedure of this type has already been implemented for body-tinted glazing materials, and a similar procedure for coated materials is underway. Another NFRC task group is developing a procedure to predict the properties of laminates from the measured optical properties of the individual layers. The optical properties of large complex systems including shading devices can be measured with the scanning radiometer.

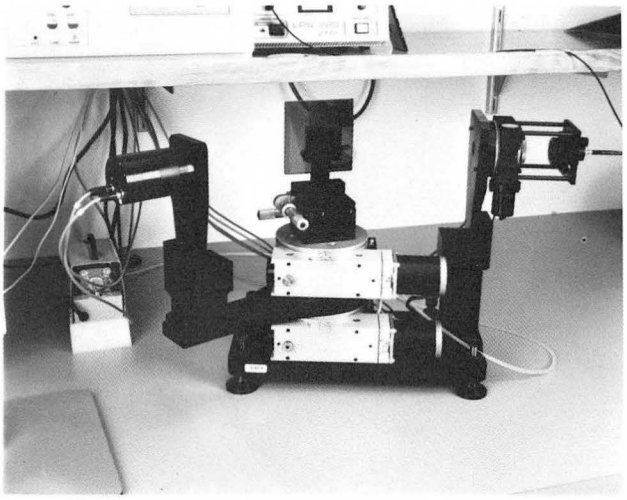


Figure 7.

Experimental apparatus for measuring the angle-dependent radiometric properties of coated glazing materials. (CBB 933-1718)

Solar Heat Gain

Solar heat gain is the most complex and variable of the fenestration energy flows. It can provide beneficial heating in winter but may become detrimental to comfort or increase space conditioning loads in summer. Utilization of its light component can provide energy benefits year-round. Optimizing the way that fenestrations in all orientations and associated building systems (e.g., lighting and HVAC controls) treat solar gain would provide a major opportunity for improving building energy efficiency, but this is currently limited by the tools available for determining fenestration performance. At present, it is difficult to correctly analyze the performance tradeoffs for simple glazings, and the degree to which fenestrations consisting of simple glazings can optimize performance is limited. For complex fenestration that uses sophisticated sun-control systems, which should be more energy-efficient, analysis with current tools is virtually impossible. Our objective is to develop experimental facilities and analytical models that can accurately characterize the daylight and solar heat gain from fenestration systems of arbitrary complexity. We conduct a wide range of activities to establish the facilities, tools, and data to address these problems.

Bidirectional Scanning Radiometer/ Photometer Facility

We have built a large, automated scanning radiometer/photometer facility for measuring the average optical properties of non-specular and spatially heterogeneous layers of fenestration systems (Fig. 8, next page). It measures the average outgoing radiance and luminance from a moderate-sized sample (approx. 7 in. × 7 in.) for a fixed incoming and outgoing direction, and automatically scans these over the full incident and outgoing hemispheres. It can measure both transmitted and reflected radiance/ luminance. Designed to provide basic performance data both for solar heat gain and daylighting studies, in 1992 it was utilized primarily to develop a method of predicting the solar heat gain through complex glazing systems and in 1993 will be used to support the development of voluntary window ratings (NFRC). It is also available to outside users.

Solar-Optical Properties of Complex Fenestration Systems

In a cooperative DOE/ASHRAE-sponsored project to develop a method of predicting the solar heat gain through complex fenestration systems, a mathematical method of combining measurements made with the bidirectional scanner of averaged

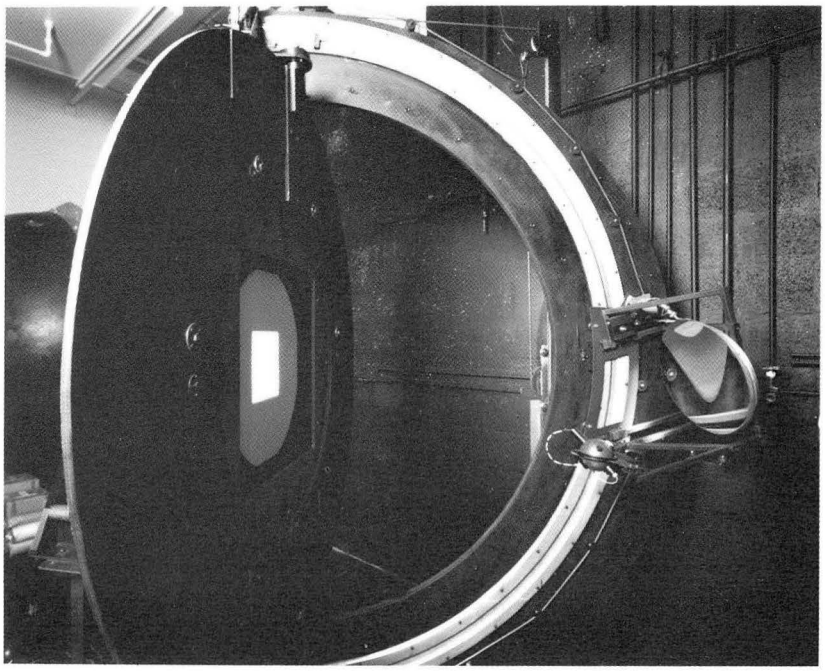


Figure 8.

The Bidirectional Scanning Radiometer/Photometer Facility. The detector assembly (right) simultaneously measures radiance and luminance and moves along a semicircular track which in turn swings around a fixed axis to produce a scan of the entire outgoing hemisphere. The detector arm, shown here in position for a transmission measurement, also swings to the front of the sample plane at left for a reflection measurement. (CBB 900-8718)

properties for non-specular shading elements (e.g., shades, blinds) with tabulated glass properties has been developed. The resulting solar-optical transmission and absorption is used to derive the system's solar heat gain coefficient (the fraction of incident solar energy that enters the building space), with the inward-flowing fraction of the solar energy absorbed in each layer derived from MoWiTT measurements (see "Field Measurement of Fenestration Thermal Performance," next page). The resulting calculation method is then validated by comparison to MoWiTT field measurements.

In mid-1992 we completed this analysis for the first of several candidate fenestration systems, a double-glazed window with an interior shade, and showed that the method produces a calculated solar heat gain coefficient (Fig. 9) in good agreement with MoWiTT measurements. During the remainder of 1992, we extended the analysis to a number of other fenestration systems to demonstrate the wide validity of the approach.

During 1993 we will begin the process of utilizing this new method as a basis for developing solar heat gain ratings for complex fenestration systems.

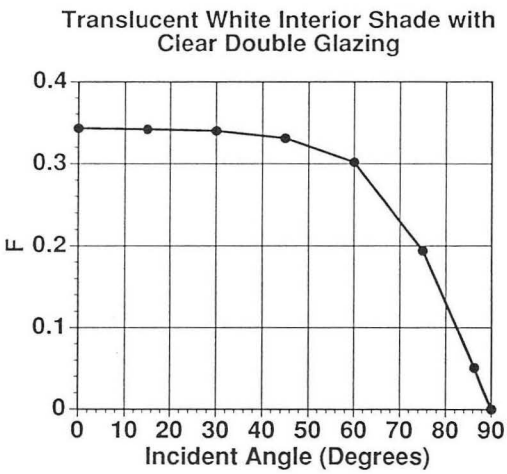


Figure 9.

DOE/ASHRAE Project: The solar heat gain coefficient, F, for a double-glazed window with interior white shade as a function of incident angle. This curve represents the calculation of a fenestration system property from bidirectional scanner measurements on the shade combined with published glass data, using the newly developed calculation method.

Daylighting

Lighting is one of the largest electrical loads in commercial buildings. An efficient daylighting design can displace 70% of the lighting energy requirements. The prediction of quantity and quality in the luminous environment is essential for energy-efficient daylighting design. Over the years, we have developed a range of daylighting analysis and design tools, continuously expanding modeling capabilities and improving calculation accuracy. Further improvements to our daylighting simulation program, SUPERLITE, are in progress to allow modeling of more sophisticated daylighting approaches such as complex sun-control systems and shading devices. We have developed a new method, Integration of Directional Coefficients (IDC), which allows daylight analyses of fenestration

Figure 10.

The MoWiTT facility at its field test site in Reno, NV. The windows are mounted in the two room-sized calorimeters of the facility. (CBB 923-3483)

systems and spaces of arbitrary complexity at any time over the course of an entire year. When combined with the DOE-2 energy analysis program, the IDC method allows us to predict the total energy and demand impact of advanced materials and systems, considering complex dynamic control strategies.

SUPERLITE was selected by an International Energy Agency (IEA) task group as a primary tool for a multinational daylighting research effort. In 1992 we completed a new version of SUPERLITE that models electric lighting. Further collaborative development work with the IEA group will improve the ease of use of the microcomputer version of the program by linking its input to a CAD program and enhancing its output capabilities. The ultimate goal of this work is a tool that can be used by designers to improve the use of energy-efficient daylighting design strategies.

The IDC method is based on a combination of scale-model photometry and computer-based analytical routines. Through scale-model photometry the IDC method allows the modeling of fenestration systems and spaces of arbitrary complexity, while through computer-based analytical routines it allows daylight prediction at any time over the course of an entire year. Scale-model photometry in our scanning radiometer is used to measure a comprehensive set of "directional illuminance coefficients" for any interior point of interest (e.g., the workplane), using a physical scale model of the space and the fenestration system. These directional coefficients are then integrated over any sun/sky/ground luminance distribution to provide daylight illuminance levels at any time of the year. The resultant comprehensive set of daylight factors are then used with the DOE-2 energy analysis program to determine hour-by-hour daylight levels and energy impacts over the entire year.

In 1992 we used the IDC method with the DOE-2 program to successfully analyze the energy performance of complex fenestration systems such as innovative skylight designs, holographic glazings, Venetian blinds, light shelves, and light pipes. Further studies of these systems will continue in 1993 in conjunction with improvements to the IDC method, with the ultimate goal of making the method widely available to researchers and designers.

Field Measurement of Fenestration Thermal Performance

The increasing variety and sophistication of fenestration products available, the move to develop energy labels for these products, and the development of programs to consider utility investments in improved end-use energy efficiency on the same basis as investments in new capacity all augment the need to measure fenestration performance under field conditions. Measuring the performance of highly optimized window systems in a realistic way is a formidable measurement task, requiring specialized non-steady-state calorimetry on a scale never previously attempted.

To perform these measurements, the Mobile Window Thermal Test Facility (MoWiTT) was designed, built, and calibrated. In developing this facility (Fig. 10), it was necessary to solve the problem of doing calorimetry on a room-sized enclosure (which would normally require careful maintenance of constant equilibrium conditions) in the presence of solar fluxes and changing outdoor temperatures, both of which control the behavior of a fenestration system. We solved this problem by using a large-area heat flux sensor (developed as part of the project) and a very sophisticated measurement of the heat extracted from the calorimeter by its cooling system. The MoWiTT began operation in 1986 at a field-test site in Reno, Nevada.

In 1992 we completed a four-year study using the MoWiTT to determine the inward-flowing fraction of absorbed solar energy in specific layers of complex fenestration systems. This study was used as part of the project described under Solar Heat Gain above. Separate MoWiTT measurements were also used in the validation stage of that project. We completed a detailed analysis of systematic measurement errors in nighttime U-value determination that established the MoWiTT accuracy as comparable to that of the best laboratory hot-box facilities, in spite of the fact that measurements are made under the much more difficult circumstance of time-varying exterior conditions. In a cooperative industry-supported study we established that a durable low-E coating applied to an exterior storm window produces the same improvement in performance that the same coating would produce in a sealed

insulating glass unit (Fig. 11), and in another industry-supported project we began the study of selective glazing performance.

In 1993 we will use the MoWiTT to test solar heat gain calculation schemes under consideration as a basis for window performance ratings. We will also continue our studies of selective glazings and continue to test emergent window technology with fenestration industry and utility support. Industry is interested in field-test data from the MoWiTT to guide development of new products and designs, while utilities want to establish the benefits of including particular types of window improvements in their efficiency incentives programs. These field measurements from the MoWiTT have the potential for removing uncertainties about window performance that have slowed progress in implementing energy-efficient building design for the past decade.

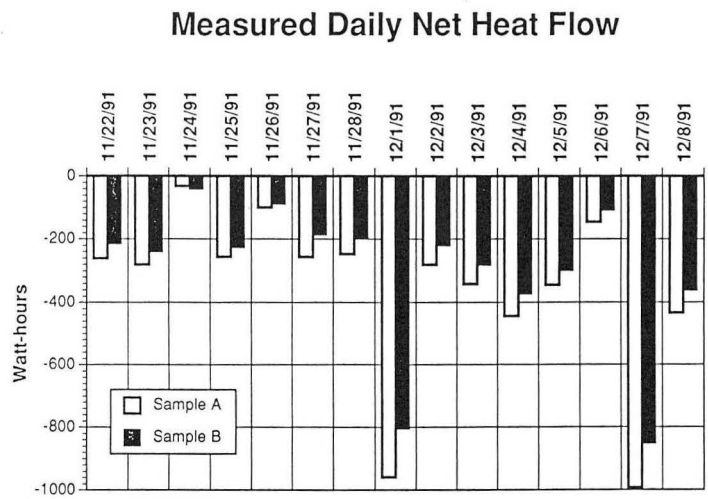


Figure 11.

Low-E Storm Window Performance: MoWiTT measurements in an industry-sponsored study demonstrated that a low-E coated storm window applied to a single-glazed prime window (Sample B) produces lower daily heat losses than an identical window with an uncoated storm window (Sample A). These winter measurements were made simultaneously using the two side-by-side MoWiTT calorimeters.

Building Applications and Design Tools

The development of new glazing materials and experimental determination of fenestration system performance must be complemented by defining how such information benefits the building design community. Our objective in the applications area is to utilize the knowledge gained from our basic science research efforts in real-world buildings and to develop the tools that are necessary to disseminate and apply this information.

Nonresidential Building Simulation Studies

Our nonresidential studies have focused on the development of a computer program called COMFEN. This program complements the RESFEN program discussed below. COMFEN calculates the incremental energy and cost performance of fenestration for a prototypical commercial building module. Users have the ability to vary fenestration size, U-value, shading coefficient, visible transmittance, desired lighting level, lighting power density, and daylighting strategy. Future versions of COMFEN will eventually be used to assist the National Fenestration Rating Council in developing energy rating labels for nonresidential windows. We completed an in-house test version of COMFEN this past year and plan to modify the program during the coming year.

A new methodology was developed for analyzing the annual cooling and lighting electricity use and peak demand associated with varying fenestration and lighting strategies in nonresidential buildings. Using regression analysis procedures, we characterized electric energy and peak performance patterns as a function of *solar aperture*, defined as the product of shading coefficient and window-to-wall ratio, and *effective daylighting aperture*, defined as the product of visible transmittance and window-to-wall ratio. Optimum performance prediction is easily facilitated by defining the solar and effective daylighting aperture values that minimize annual energy consumption and peak demand.

Envelope and Lighting Technologies to Reduce Electric Demand in Commercial Buildings

The goal of this project is to develop and promote advanced integrated building systems incorporating high-performance envelope and lighting elements. The largest components of peak demand in most California commercial buildings can be traced to the fenestration and illumination systems, which typically impose large electrical loads for cooling and lighting. Reducing or eliminating these loads can be a cost-effective, demand-side management option for utilities. While the performance of lighting and envelope systems has improved in recent years, designers confronted with a large array of new technologies have not been successful in creating designs that achieve optimal energy performance results. The full potential of existing and emerging technologies will be realized only when they are commercially available in a form that maximizes performance and facilitates widespread application. Technologies designed and packaged as *integrated systems* and supported by appropriate tools to assist in design, specification, and assurance of performance will exert a far greater impact in the building community.

In 1991 we completed the first phase of this multiyear project, supported by

the California Institute for Energy Efficiency (CIEE) with funding from major California utilities and co-support from DOE. California utilities have been leaders in the U.S. in promoting the use of new energy-efficient building technologies. We collaborated in this project with the Graduate School of Architecture and Urban Planning, University of California, Los Angeles.

In 1992 we completed Phase 1 which included the following: completed an impact assessment of peak demand and energy consumption savings in California; developed and validated a unique experimental method coupled with the DOE-2 building energy simulation program to evaluate the daylighting performance of optically complex systems; began discussions with several potential industry partners to develop new integrated designs; and assisted several California utilities in demonstration projects where elements of our integrated system could be implemented and evaluated.

In 1993, Phase 2 will continue the development of two specific integrated envelope and lighting system designs. The prototype systems will be evaluated in a series of simulation and field tests using reduced scale models to determine thermal and daylighting performance. The first prototype is a dynamic facade system incorporating selective glazings and motorized shading. We will focus on the development of sophisticated control algorithms and hardware that can balance in real-time the daylighting/lighting benefits against the cooling loads due to lights and solar gains. The second prototype couples an independent core daylighting system with a vision window using a dynamically operated shading system. These designs use advanced optical materials and geometry to bring uniform and consistent daylight to work areas in the back of the perimeter zone. Each system incorporates control hardware and software to optimize energy, demand, comfort and performance. Both integrated prototypes are being developed in cooperation with industry partners to speed commercialization of the technologies and to assess potential market/implementation barriers to full-scale adoption. Work will also continue on planning demonstrations in an occupied building(s) to evaluate energy performance and occupant comfort and productivity.

Residential Buildings

The focus of our residential work continues to be development of an annual energy rating methodology for windows for the National Fenestration Rating Council. We continued development and improvement of the computer program RESFEN in response to industry requests for expanded modeling capabilities. This program calculates the incremental energy and cost performance of fenestration for several residential building models. Users have the ability to vary window size, window type, U-value, shading coefficient, infiltration levels, and interior and exterior shading systems. Improvements made to the program included the ability to analyze additional orientations and residential configurations, revised infiltration algorithms, and calculation of peak heating and cooling loads. We will continue to revise and augment this program during the coming year. Studies will be undertaken to investigate the viability of utilizing an hour-by-hour calculation scheme based on the DOE-2 program with a reduced set of weather data. Such a procedure would facilitate analysis of arbitrary residential configurations in many geographic locations.

We also began prototyping a builder/consumer version of the RESFEN program. This version takes the form of an interactive kiosk with a touchscreen and will be initially used and evaluated in several local building supply stores in the San Francisco Bay Area. Online basic information about residential windows, as well as advice on selecting specific window products, will be provided in addition to the energy consumption results.

To complement the RESFEN computer program, we have been updating the text-based Residential Window Design Guidelines handbook that was completed last year. The guidelines provide fenestration design information to architects, engineers, builders, and homeowners. Topics addressed in the guidelines include an overview and historical discussion of residential windows; specific design recommendations regarding view, lighting, ventilation, insulation, solar heat gain, condensation, and acoustics; material selection and installation including glazing products and framing; and regional climate guidelines on energy performance. We will complete an industry review of the guidelines during the coming year.

Advanced Design Tools: Building Design Support Environment

The Building Design Support Environment (BDSE) is a framework of computer-based applications to assist building designers in more easily addressing energy-related design issues and considering new, energy-efficient technologies. We began to explore new concepts for computer-based architectural design tools several years ago, after observing that energy efficiency remains a low priority in standard building design practice, mainly because of lack of time and expertise to predict the energy-related performance of buildings. Our initial image of an intelligent and integrated package that would contain the required expertise and automate the energy-related performance prediction has since been developed into an experimental prototype, the BDSE. This integrated computer-based environment uses various new computer technologies, such as hypertext, multimedia, and expert systems, in order to more effectively reach and engage building designers.

Our major development effort in 1992 related to the BDSE was development of a module for the DOE AEDOT prototype. Our module determined the daylighting and glare performance of a building space and calculated annual energy performance. The demonstration module also contained photorealistic images of typical spaces calculated using LBL's RADIANCE program. At the end of the year, we initiated a major collaboration effort with several utilities and the Electric Power Research Institute (EPRI) to develop a more usable version of the DOE-2 energy simulation program. We will use concepts developed as part of the BDSE to develop an "Energy Design Advisor" which will help convert this new version of DOE-2 from an "analysis" tool to a "design" tool.

Technology Transfer

In order to influence energy efficien-

cy trends in the United States, our results need to be communicated to other researchers and to professionals in the building industry. We use a variety of media to reach a widely varied audience, including trade journal articles, network and utility-based television production, and exhibits. We continue to develop more effective approaches to technology transfer by experimenting with new electronic and optical media. Our primary audiences include other national and international research and development groups, professional and industrial societies, manufacturers, and educational institutions. We continue to develop improved design tools and handbooks, to carry out design assistance studies, and to sponsor workshops and meetings with manufacturers, design firms, educators, and utilities.

In an effort to communicate with a variety of building industry audiences, both professional and consumer, we continued to focus on the uses of computer-based information systems and technologies. With limited resources for technology transfer, we explored and tested an electronic bulletin board and smart fax systems, CD-ROM publishing, and point-of-purchase consumer information marketing. All this media can reach larger decision-making audiences with a minimum amount of effort.

The electronic bulletin board initially will link the National Fenestration Rating Council (NFRC) and an electronic mail community of manufacturing professionals. The WINDOW 4.0 computer program and 80-page manual were incorporated into a CD-ROM published by the Architects/Engineers/Contractors Systems conference (Fig. 12), and distributed to over 15,000 building industry professionals. A consumer-based interactive information kiosk environment was developed for the RESFEN window calculation program (Fig. 13). The kiosk will be market-tested in building and window projects businesses.

A new kiosk design project was launched for the U.S. Department of Energy to highlight buildings research. As a part of this effort, a prototype multimedia kiosk was presented at the opening of the new Energy Child Development Center at U.S. DOE headquarters in Washington, D.C.

Building on our multimedia development experience, we also continued to explore new opportunities and sources of funding to develop prototype information projects. Lawrence Berkeley Laboratory funded the development of a LBL Information Kiosk for use in both a new visitor center complex and for off-site community relations events. We are talking with utility audiences about computer-based information in the belief that timely and entertaining professional education is critical to integrating new technologies and know-how into practice. Finally, we joined in initiating the TerraMedia™ Collaborative with the International Institute for Energy Conservation in Washington, D.C. to develop a multimedia training system for an international energy efficiency policy audience. In addition, we continued to design portable information exhibits for several research projects that were used in a variety of conferences, including the Global Forum/Rio exhibition.

Figure 12.

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.

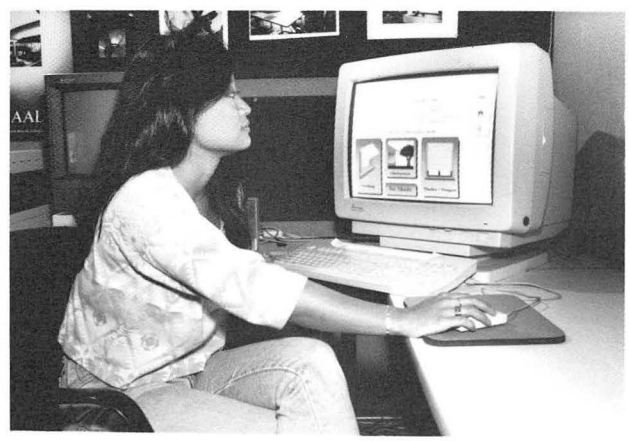


Figure 13.

The RESFEN Kiosk has been developed using multimedia technologies to deliver consumer-level residential window selection information at the point of purchase. (XBC 9211-9885)

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Lighting Systems

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New, efficient lighting technologies and strategies have the potential to save 50% of the lighting energy consumed by our nation, an amount which is about 12% of total U.S. electrical energy sales. Annually, these savings would amount to some 220 billion kilowatt-hours of electricity, valued today at more than 16 billion dollars. The significance of these savings can be appreciated by considering economic projections that predict a doubling of present commercial floor space by the year 2020. The 220 billion kilowatt-hours of saved energy would allow desired lighting conditions for the new space without the creation of new electrical generating capacity; in this scenario, the United States would realize additional capital savings of more than $100 billion.

To help achieve this more energy-efficient economy, the Office of Building Technologies of the U.S. Department of Energy has established a program of research activities and technology transfer to the lighting community (manufacturers, designers, and users). This program, which represents a unique partnership between a national laboratory-university complex and industry, facilitates technical advances, strengthens industrial capability, and provides designers and the public with needed information.

Past successes from this effort include: development of the high-frequency, solid-state ballast for improving the efficiency of fluorescent lamps; the Controlite computer program that enables designers to determine the energy and economic benefits of lighting controls in the workplace; assistance in developing the compact fluorescent lamp; important information on how lighting can affect productivity and visual functions; and determination that lamps providing scotopically rich spectra can supply major energy savings in a highly cost-effective manner.

Our program is now actively pursuing the development of more energy efficient light sources through technical concepts employing a variety of ingenious methods for operating lamps at very high frequency without electrodes, and possibly without mercury. These approaches will improve efficiency, longevity and environmental quality. In addition, the program is developing comprehensive strategies to optimize the benefits obtained by utilizing our new technical approaches to improve the efficacy of lighting fixtures and lighting control systems. This effort is assisted by the use of computer concepts to display realistic, visual simulation of the lighted workplace. In its study of the relation between lighting variables and visual function, the program is identifying visual responses to lighting conditions—research results that can lead to innovative new lighting products that improve both energy efficiency and human productivity.

The program has identified new long-range technical concepts that have significant potential payoff. These concepts include: development of more efficient fluorescent lamp phosphors, mercury-free lamps filled with novel gases, advanced fixture systems that overcome the inefficiencies associated with overheating and light capture, and the use of the spectral quality of lighting to optimize performance and comfort.

This interdisciplinary program encourages innovation in the industry and accelerates the societal benefits obtainable from a more cost-effective and energy-efficient lighting economy. Because of its comprehensiveness, the program is unique in the United States.

Since its inception in 1976, the LBL Lighting Program has produced more than 168 reports and publications. These reports, available to the public, document research on solid-state ballasts, operation of gas-discharge lamps at high frequency, isotopically enriched fluorescent lamps, energy-efficient fixtures, lighting control systems, and visibility and human productivity. In addition to its research activities, the internationally recognized interdisciplinary staff is involved in a variety of professional, technical, and governmental activities.

The Lighting Program combines staff of LBL with those of the University of California (Berkeley) School of Optometry and the University of California School of Medicine in San Francisco (UCSF) to provide a high level of interdisciplinary expertise.

We highlight here the accomplishments realized in 1992—and those planned for 1993—by each of our three major projects: advanced light sources, building applications, and impacts on visual performance.

Advanced Light Sources

The work on advanced light sources undertakes development of new highly efficient lamp technologies and light sources. To understand what can be accomplished in this area, consider that the most efficacious four-foot fluorescent lamp, operated at a medium-high frequency with today's best technology (20 kHz), has a luminous efficacy of approximately 100 lumens of light output per watt of electrical power input (lamp alone). Although this is more than five times as efficient as an incandescent lamp, still greater efficacies are possible. Theoretically, white light can be produced at almost 350 lumens per watt; the advanced lamp technology program is developing the engineering science that will help achieve a target efficacy of 150 lumens per watt within the present decade.

In the area of fluorescent lamps, our present directions for accomplishing efficiency improvements focus on three major energy-loss mechanisms: electrode losses; energy loss by lamp phosphors in their conversion of ultraviolet (UV) radiation to visible light; and self-absorption of ultraviolet UV radiation, which eventually leads to losses by electron quenching of excited mercury atoms.

Energy losses associated with electrodes can be eliminated by exciting the lamp plasma at radio frequencies (RF). The problem is to find an efficient method for coupling the RF energy into the lamp without causing new losses.

One of the methods developed at LBL uses a plasma wave-guide coupling principle. This wave-guide mode of operation uses RF frequencies in the range between 100 and 500 MHz, permitting lamp excitation without electrodes. This fluorescent lamp, which operates in the transverse magnetic (TM) mode, shows some promise of providing an efficient means of both creating and energizing the lamp plasma. The TM mode fluorescent lamp operates without starting circuits and should have an extended lifetime because of the absence of electrodes.

Reducing the causes of energy loss in the phosphors requires alteration of lamp phosphor material. The materials used today convert each UV photon into slightly less than one visible photon, on average. Improving this conversion rate would increase the efficacy of low-pressure discharge lamps. Although a UV photon generated in a typical fluorescent lamp has sufficient energy to permit conversion into two visible photons, this process must occur quickly on an atomic level if it is to prevent heat-producing collisions. We can improve the chance of multiple photon emission by using higher energy UV photons than those that normally occur with a mercury discharge. Rare gas discharges using neon provide such high energy UV photons. On this basis, LBL and GTE Lighting are working together on a phosphor chemistry project designed to discover whether multiple photon phosphors are feasible.

If these research projects reach technological and commercial fruition, future fluorescent lamps would operate at megahertz frequencies without electrodes and would be coated with a multi-photon phosphor. Such lamps would have an efficacy of more than 150 lumens per watt, more than doubling the efficiency of today's best fluorescent lamps.

Our other lamp technology research concentrates on high-intensity discharge (HID) lamps, which could be made both more efficient and dimmable if operated without electrodes. High-frequency operation is required to excite the lamp plasma in an electrodeless mode. Electrodeless operation would also allow us to use compounds that have desirable light spectrum and gas fills that do not require mercury. Many of these possibilities are currently excluded because they would harm electrodes. An efficient mercury-free electrodeless lamp that could be dimmed without observable spectral changes and provide instant restrike would herald a new age of light sources. It would improve energy efficiency, have the optical characteristics desired by lighting designers, and yet be environmentally benign.

Besides the light source itself, the other important component of the lamp is the electronic power supply which must convert incoming wall-plug power to the high-frequency power required by the electrodeless light sources. Because of the total absence of commercially available, efficient power supplies operating at power levels and frequencies needed for our light sources, we are also embarking on a program to develop the necessary power conditioning. The physical nature of the coupling between the light source and the power supply means that the research is highly interactive between the power supply and the light source. Concepts such as the Type-E Amplifier, which provides a method for high-frequency switching of voltage at zero current and current switching at zero voltage are under consideration.

Replication Study of RF-Driven Low-Pressure Lamps

Increases in efficacy (lumens per lamp watt) of approximately 40%, when compared to the same lamps conventionally operated at 60 Hz, have been reported in previous annual reports for commercial fluorescent type lamps (F15 T8; G15 T8) when driven at RF frequencies (~200 MHz). Our replication studies under the same conditions show a range of about 18% to 23% improvement; this amount is mostly achieved at 25 kHz operation. The addition of a few percent increase in efficacy with RF operation over 25 kHz operation appears possible. However, lowering argon pressure from the conventional value to about 1 torr permits an additional increase in efficacy of approximately 15%. Thus, combining the RF operation with the argon pressure effect can yield improvement of about 40%.

Measurements of possible losses under RF conditions due to a variety of confounding mechanisms have been examined. These confounders include attenuation of the 254-nm radiation in the glass envelopes; RF absorption in the glasses; losses of power in the launchers (or cups) and matching networks; the possibility of filaments absorbing RF power; and the configurations of metallic couplers used to transfer RF power

into the lamp. No loss mechanism has been found that can account for the earlier purported large efficacy improvement. The replication studies at best indicate the possibility of about 5% improvement between 25 kHz operation and RF operation (100 MHz to 250 MHz).

Lowering the pressure of the argon gas from the conventional value of 3.5 torr used in commercial fluorescent lamps to the value of 1 torr allows for about a 15% improvement in efficacy. The application of this pressure effect is detrimental to electroded lamps because of the significant lifetime reduction, but it can be used for electrodeless lamps without any adverse lifetime effects. An efficacy improvement of 20% over 25 kHz operation (or 40% over the 60 Hz case) would be achievable by combining the RF effect with the argon pressure effect.

Present high-frequency solid-state ballasts achieving 90% efficiency operate fluorescent lamps in the 25 kHz range. Hence, the RF power conditioning for electrodeless lamps should have comparable efficiency to make them competitive on an efficiency basis. While the energy benefits of an RF lamp may be marginal, we have defined a major technical breakthrough on longevity. Electrodeless lamp lifetimes should be three times greater than present fluorescent lamp life (3 × 20,000 hours) and should be easily achievable. The ultimate lifetime will be dependent on the electronic package rather than the lamp itself.

Because of this lifetime feature which is a powerful force for market entry, the FY 1993 program will continue to explore possible mechanisms for improving the energy efficiency of RF-driven fluorescent lamps. Our measurements show power losses of 30% to 40% in compact fluorescent lamps due to the electrode losses. If these losses can be significantly overcome in an RF mode while maintaining or increasing lumen output, the combination of efficiency and lifetime enhancements will provide a highly attractive technical innovation.

Electrodeless HID (High-Intensity Discharge) Lamp

Because present compact fluorescent lamps do not achieve the lumen output of the higher wattage incandescent lamps while maintaining their small size, there is a significant opportunity for this technical approach to fulfill the need for a highly efficient replacement. As mentioned above, the electrodeless HID approach also offers the opportunity to employ mercury-free lamp fills. Two possible candidate lamps have recently emerged from the light source community, namely the sulfur lamp and the cluster lamp.

The sulfur lamp developed by Fusion Systems Corporation was lit at LBL in August 1992 in cooperation with personnel from Fusion Systems Corporation. The lamp was lit in a 1/4 wavelength transverse electric mode (TEM) (coaxial mode) cavity resonant at 460 MHz. The cavity was designed to provide both frequency resonance and impedance matching in a single RF structure. Frequency resonance was determined by the length of the center post while impedance matching was controlled by a sliding mechanical tap to the center cavity post. Optimum coupling to the sulfur lamp was provided by conforming the cavity center post tip to maximize the electric field gradient that coupled to the lamp. With this coupling mechanism, sulfur lamps were brought to incandescent brightness at power levels from 150 watts to as low as 60 watts. The lamp was operated continuously for several hours and appeared completely stable. Surface temperature of the quartz envelope was measured with an optical pyrometer. Figure 1 (below) shows the cavity with the power conditioning equipment and pyrometer.

Multi-Photon Phosphors

Based on theoretical calculation during FY 1991, additional experimental measurements were carried out at the Brookhaven National Synchrotron Light Source (BNSLS) in order to explore a number of these newly proposed phosphor systems for multiple-photon emission (MPE). One of the new processes we have considered is referred to as the InterBand Auger (IBA) process. The promising phosphor candidates identified by the theoretical work,

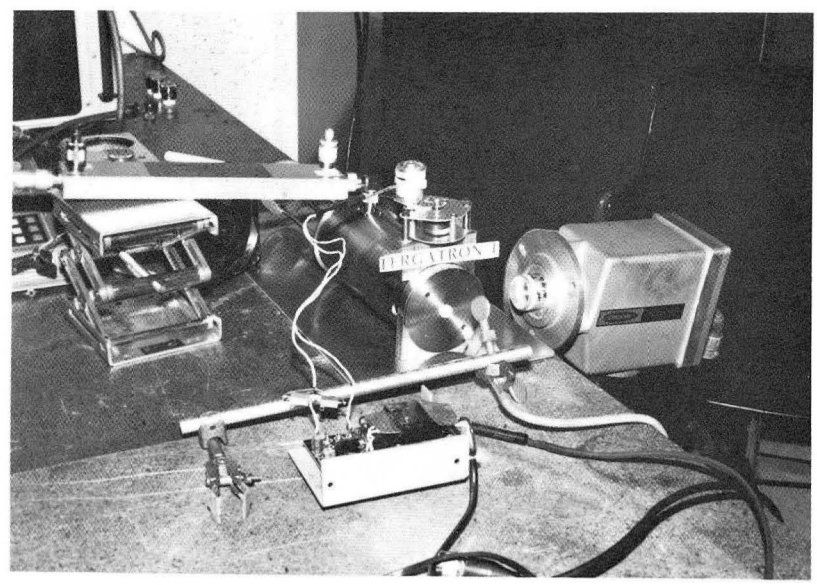

Figure 1.

The experimental set-up used to power the sulfur lamp. The lamp is inside the cavity labeled Fergatron I with the pyrometer on its right side viewing the lamp through a port in the cavity. (XBC928-6702B)

($Ba_2TiP_2O_9$, Y_2O_3:Eu, Zn_2SiO_4:Mn, and YBO_4:Eu) were studied at the BNSLS during the first two weeks of November 1991. The Y_2O_3:Eu and Zn_2SiO_4:Mn again demonstrated IBA with quantum efficiencies (QE) greater than unity at excitation energies above 14 eV, respectively. Of the phosphors evaluated for the first time, only the $Ba_2TiP_2O_9$ sample demonstrated unequivocally the IBA MPE process. Its QE was greater than one for excitation energies greater than 17 eV. The existence of the Impurity Assisted InterBand Auger (IAIBA) was also studied at the BNSLS (suggested by theory) with the results of the measurements inconclusive. As in our previous work, we saw the onset of QE increase for excitation energies which would be consistent with the presence of the IAIBA process. However, no definitive results (QE>1) for excitation energies less than twice the band gap of the host lattice were achieved. A statistical simulation method was also attempted with negative results. We were unable to reduce system noise to the level necessary for detection of our signal.

Last year we reported lower than expected light emission from a low pressure rare gas discharge lamp coated with the multi-photon phosphor Zn_2SiO_4:Mn. The low value was blamed on the phosphor application technique, which was suspected of causing a surface contamination, namely, Na desorbed from the glass and deposited on the phosphor surface. We attempted to remedy this by using Nonex hard glass which contains five times less Na than the previous soda lime glass. These lamps were again filled with either 1 torr of Ne, Ar or Xe and coated with the phosphor. Light emission was still an order of magnitude below expectation. A more elaborate experiment was carried out where we made separate measurements on the vacuum UV production and on the emissions from the phosphor. These measurements indicated the vacuum UV production was as expected and that the lack of emission from the phosphor was indeed a phosphor problem and not a result of insufficient UV photons. The problem of eliminating the phosphor surface degradation remains to be solved.

Building Applications

Real energy savings depend on the transfer of energy-efficient technologies and strategies to the lighting community. Our building applications activities aim to assess the technical performance of energy-efficient lighting technologies, to develop methods to improve component performance, and to describe and model the synergistic effects of combining different technologies with appropriate lighting geometries and controls. Our analysis also uses the relationship between visual performance and physical aspects of lighting, illumination level, distribution, contrast, and glare. As part of this effort we have developed a computer program that accurately simulates illuminated spaces and their contents. Using simulated scenes that are visually indistinguishable from real photographs, we can model effects of changes in the illumination systems. Validation of luminance values produced by these simulations requires physical measurements of luminances in complex environments. To obtain actual luminance values, we use novel techniques for determining real luminances of interior environments containing complex objects.

In a highly successful technology transfer activity, we have examined engineering approaches to reduce lighting losses associated with the thermal and optical factors of conventional lighting fixtures.

A number of approaches have led to disclosures and patents, with the fixture industry actively incorporating many of these concepts into their present market portfolio. The culmination of the building application efforts will be a variety of advanced luminaires, concomitant analysis, and visual simulation of the proposed application. The totality of these efforts represents the most compelling tool for implementing energy-efficient lighting. All of these R&D efforts include substantial technology transfer activities with the lighting industry in order to assure a rapid flow of our concepts into the market.

Energy-Efficient Luminaires and Thermal Control Devices

Several approaches have been developed for improving the thermal performance of fluorescent fixtures. These techniques have been successfully applied to a number of fixture systems, notably full-size and compact fluorescent fixtures.

For the four-foot fluorescent luminaires, two main concepts have been explored: the thermal bridge and convective cooling. The thermal bridge combines a liquid heat sink with a conductive metal bridge, which uses cooling fins external to the fixture shell.

We have continued to fine tune a number of approaches to improve the performance of compact fluorescent fixtures. These include: convective cooling, the liquid heat sink, and a metal spring bridge with dissipating fins. Lamp burning positions (base up or base down) were found to be a key determinant of system efficacy.

Successful and practical techniques to improve thermal performance were demonstrated, and several technical papers were written and published. Fixture manufacturers and utilities have been anxious to keep abreast of the latest developments and have facilitated our technology transfer. A number of simple and practical approaches for improving the thermal performance of recessed downlights with compact fluorescent fixtures (CFL) were accomplished. Efficiency improvements between 15% and 20% have been systematically established. These approaches have rapidly been implemented by a large segment of the fixture industry. The improvements are quite important

because they allow the substitution for a 75-W incandescent rather than a 60-W incandescent, thereby increasing the CFL market share.

During FY 1993, further refinements of thermal management concepts will continue. In addition, we plan to undertake the development of a high-efficiency centralized lighting system. This concept will combine high power and more efficient light sources with a light pipe distribution system. System prototypes will be developed and a cooperative program will be initiated with TIR Systems, Ltd. and the 3M Company, both of whom have indicated strong interest.

In 1993, we also plan a major effort to improve the efficacy of recessed open downlights by implementing new concepts developed for convective cooling. We will measure performance responses to different approaches and conduct photometric studies to assess any optical losses associated with the convective strategies. During 1993 we expect to begin examining approaches that apply the thermal bridge concept to standard linear fluorescent systems.

Quality Illumination and Performance

One of the major activities of the Illumination Engineering Society of North America (IESNA) is the development of light-level recommendations. Although not prepared as a legal standard, the recommendations of the IESNA are often the de facto standard. As such, their light-level recommendations have major implications for lighting energy consumption in the United States. The present recommendations have been in place for more than a decade and the IESNA is presently tasking its technical committees to issue new and revised recommendations. A major reason for this action is that the present recommendations are based on consensus opinion of a body of expert practitioners and have no clearly defined analytical basis. The principal technical committee undertaking the revision has proposed that the new recommendations be based on the experiments and models of visual performance.

Over the past years, we have been involved in the analysis of visual performance and have concluded that a major flaw of the IESNA recommendations is their failure to take into account the economic aspects of light level. To this end, we have been incorporating straightforward benefit/cost analysis in the modeling of visual performances and have derived consequences for light level recommendations. During the past year, we have developed a method for analytically determining light levels by finding the optimum point of light level. This occurs when the economic value of performance benefits to workers due to increased lighting is incrementally less than the cost of the added energy and equipment. This analytic procedure can be applied to all models of visual performance. Our methodology, when applied to the model of visual performance used by the IESNA in their proposed revisions, yields very different values for light level recommendations. Differences between the IESNA numbers and our values can be greater than one order of magnitude, with the IESNA recommendation generally on the higher side. These results were presented at the 1992 annual national meeting of the IESNA.

Our work is the first to explicitly combine both the benefits and costs of lighting to derive a light level recommendation. These results will have a major impact on energy use for lighting. We expect to actively pursue further interactions with the IESNA on this issue during FY 1993.

In addition to introducing the economic reality into the IESNA light level issue, we have completed an extensive study of 16 subjects who are reading words as a visual performance task. We determined how performance (reading speed) relates to light level and contrast, with size of the letters as the critical parameter. The model developed to support the data represents a major refinement over past models and should replace earlier models with less predictive power.

More importantly, this study has led us to the development of a simple instrument that can be taken into the field to test whether a particular worker has an adequate light level for a particular task. The instrument has been built, and we plan to test it during FY 1993 in an office building as part of our lighting quality work under the auspices of Caltrans (the transportation agency of the State of California).

Computer Imaging

At the beginning of FY92, several new features were added to the Radiance program. These include: enhancements for daylighting systems and glare analysis, and resulting visualization. In addition, a report on improved interreflection calculation was written, and the results were presented at the 1992 Eurographics Rendering Workshop. A new anisotropic reflection model was developed and validated, using data gathered with the imaging gonioreflectometer. A report on the reflectometer and reflectance model was written and the results presented at the 1992 SIGGRAPH Conference. At the behest of DOE headquarters, Arthur D. Little's market survey is getting underway, and we are providing software and hardware support as needed by the subcontractors.

Impacts of New Lighting Technologies on Visual Performance

We can achieve major benefits to lighting energy efficiency by studying human responses in order to provide the best visual effectiveness per watt of input power. Determination of visual effectiveness in terms of human subject responses requires an understanding of how lighting affects performance. This knowledge is an essential input to technology development especially considering that the end purpose of lighting is for human benefit.

Spectral Effects (Human Response to Electric Lighting)

In a series of studies done over the past three years, we have shown that the rod photoreceptors of the eye have significant effects on vision functions at light levels typical of building interiors. These studies (for conditions of full-field of view and adults 20-40 years of age) showed that pupil size was predominantly determined by the scotopic spectral content of the ambient illumination and also that brightness perception of whitish light depended strongly on the scotopic content of the viewed illumination. Thus, two general lighting illuminants providing the same level of photopic luminance of whitish light, but with different spectral distributions, will elicit both different pupil sizes and different perceptions of brightness. The illuminant with the greater scotopic luminance will yield a smaller pupil and will be perceived as brighter.

During the past year, we built a portable demonstration booth designed to show the brightness effect of scotopically enhanced light sources. The booth is a small room with white walls, measuring 7 ft. high with horizontal dimensions of 3 ft. × 7 ft. The room contains two different illuminants mounted from the ceiling to allow viewers to observe the illuminated front wall without any radiation from the lamps directly impinging on the viewers. The illuminants are color matched, i.e., they have equal chromaticity coordinates and are electrically controlled so that the person conducting the observation can switch instantly back and forth between the two illuminants being compared. One illuminant is scotopically enhanced, while the other is scotopically deficient.

The booth was taken to the national IES meeting in San Diego and more than 100 conferees participated in the comparison. About 98% of these observers claimed that the scotopically enhanced illuminant, although producing 20% less photopic luminance on the viewed wall, appeared brighter. The demonstration clearly showed the potential for energy savings solely by spectrum modification.

Recognizing the importance of this result, along with the demonstration that scotopically enhanced lighting can yield improved visual performance via our Landolt C studies, G.E. Lighting has embarked on a program of producing a variety of scotopically enhanced fluorescent lamps which will be tested at LBL during 1993.

In cooperation with the Abratech Corporation we have extended our work to include elderly subjects, investigating whether spectrally-induced pupil size differences affect the recognition of Landolt C orientation. Our hypothesis is again that smaller pupils will yield improved performance. We tested this proposition, as before, by comparing two illuminants providing the same surround photopic luminance, but with different scotopic luminances. The scotopically richer surround illumination yields both slightly smaller pupils and also better performance for the elderly. The Landolt C task is viewed on a CRT in binocular vision with its luminance independently controlled by CRT function and unaffected by the surround illumination.

The results of this study, combined with our previous study of 20- to 40-year-old subjects, demonstrates that scotopically richer light yields better performance on the Landolt C orientation task, even though task retinal illuminance is smaller. This determination supports the suggestion that energy savings can be obtained for a large segment of the population by taking advantage of visual scotopic sensitivity. If an equal level of scotopic luminance is achieved by increasing the scotopic spectral output, but obtained at a lower energy, visual performance would remain unaffected and savings would accrue.

Discomfort Glare (Lighting Ergonomics)

A second area of importance related to how lighting affects visual performance is discomfort glare. Because the trend in moving to the smaller size and more efficient light sources will increase glare response, a better understanding of possible negative user concerns is needed. Although it is relatively easy to perceive and report discomfort sensations caused by an offending light source of high luminance, no one has yet found a reliable objective correlate of discomfort glare. In order to find an objectively measured correlate of discomfort glare, we have examined electrical activity associated with the major sphincter muscle that surrounds the eye, viz the *orbicularis oculi*. We have made electromyographic (EMG) recordings using small silver chloride electrodes applied to the skin above the muscles and measured electrical potentials while lighting glare conditions have been changed. The subject preparation and apparatus are shown (Fig. 2, next page). Intensities were varied over a range of glare luminance determined by a separate procedure according to subjective ratings. For this subjective method, subjects indicated the level of discomfort by marking a visual analog scale (VAS) punctuated with four descriptors of discomfort level: perceptible, annoying, disturbing and intolerable. We have determined that the VAS

is much more reliable with less variability than the previously used BCD method (border between comfort and discomfort).

For 20 subjects discomfort glare was assessed under three conditions: 2° diameter glare source with low illumination (wall = 0.5 cd/m²), 2° glare source with medium illumination (wall = 12 cd/m²), and 1° glare source with medium room illumination. The glare source was a projector beam, 11° to the right of a fixation target on a video monitor (8° × 10°, luminance 69 cd/m²). Six different glare illuminance levels were presented for a period of two seconds. Each glare level was presented six times in a randomized order, giving 36 presentations.

EMG responses were subjected to Fourier analysis and the power frequency spectrum was determined with appropriate digital filtering used to eliminate power line artifacts. Blinking causes an artifact producing a power spectrum that is markedly different from the response to the glare source. Because of this condition, blinking can be studied independently of the glare source. The integrated EMG (IEMG) activity during exposure to the glare source was compared to the IEMG prior to exposure, to obtain an IEMG ratio (IEMG with glare/IEMG without glare). For each of the 20 subjects and a variety of glare conditions, the IEMG ratio and the VAS have been plotted as a function of glare luminance. For individual subjects, we found increasing IEMG ratio and increasing subjective discomfort with increased glare luminance. On the basis of these results, we are able to conclude that the EMG technique is a valid objective means of assessing discomfort glare.

During FY 1993, we will be preparing a technical report and manuscript for publication. In addition, we plan experiments using our EMG methods to examine the influence of the color (spectrum) of the glare source on discomfort glare. We will also examine how the equipment used to record EMG response can be simplified and made into an instrument for direct evaluation of discomfort glare in the workplace.

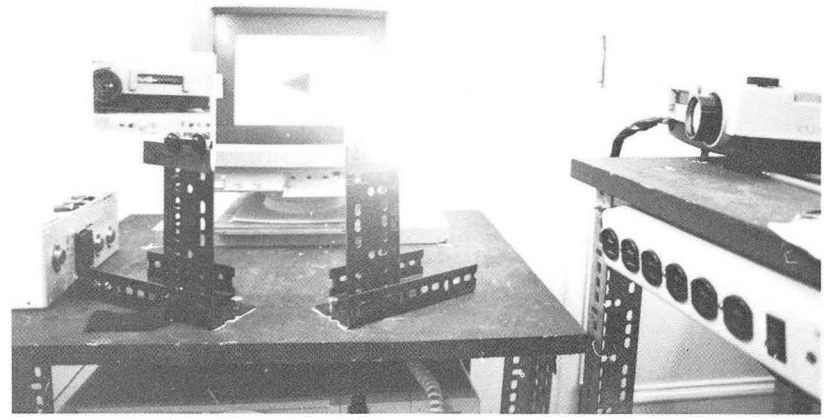

Figure 2.

View of glare test as seen by the subject, who fixates on the triangle on the CRT while the mirror projects the glare source to the eye at 8° off axis. (CBB 910-8648)

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Building Energy Simulation

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Our simulation research effort develops accurate, well-validated computer programs to assist in the design of energy-efficient and cost-effective buildings. This work includes development and maintenance of current-generation energy analysis programs—DOE-2 and the Retrofit Energy Savings Estimation Model (RESEM)—and development of advanced building performance calculation tools—the Simulation Problem Analysis and Research Kernel (SPARK) and the DOE-EPRI program.

DOE-2 is a public-domain computer program that performs an hour-by-hour simulation of a building's expected energy use and energy cost given a description of the building's climate, architecture, materials, operating schedules, and HVAC equipment. DOE-2 is widely used in the United States and in 42 other countries to design energy-efficient buildings, to analyze the impact of new technologies, and to develop energy conservation standards.

SPARK is a modular simulation environment designed for developing customized models for analysis of complex building energy components and systems.

The DOE-EPRI program is a substantially improved version of DOE-2 that is easier to use by the average designer, can simulate future HVAC technologies, and provides expert-system-based design guidance.

RESEM, the Retrofit Energy Savings Estimation Model, is a PC-based, interactive tool developed for the DOE Institutional Conservation Program to provide reliable estimates of energy savings due to energy conservation retrofits in institutional buildings.

We are also collaborating with the National Renewable Energy Laboratory (NREL) and the Passive Solar Industries Council in the development of a computerized tool that will provide design guidance for the optimal utilization of passive solar technologies in small commercial buildings.

DOE-2

With the assistance of Hirsch & Associates, we continued work on DOE-2.1E with joint funding from the DOE Office of Building Technologies, Southern California Edison Co., Pacific Gas and Electric Co., the Electric Power Research Institute, the Gas Research Institute, Pacific Northwest Laboratory, and the IEA Solar Heating and Cooling Program. Major new features in DOE-2.1E are aimed at meeting the simulation needs of the architectural and engineering research and design communities. These features include:

- *Evaporative cooling.* Models were developed for stand-alone evaporative cooling systems and evaporative cooling units integrated with conventional HVAC systems. This feature will allow cost-benefit analysis of evaporative cooling as an alternative to vapor-compression cooling systems.
- *Ice storage.* Modifications to the DOE-2 PLANT program allow simulation of a variety of cool storage systems such as ice-on-coil, ice-harvester, brine, and ice slurry. Such systems have the potential for reducing cooling costs by allowing ice to be made at night when electricity rates are low.
- *Switchable glazing.* This feature allows simulation of "smart" windows whose solar-optical properties can change according to environmental conditions. An example is electrochromic glass that can be switched from clear to reflective by changing the applied voltage in response to a control variable such as incident solar radiation. Switchable glazing has the

potential for providing better solar control than conventional glazings, with resultant lower cooling loads.

- *Glazing library.* A new window library has been assembled containing about 200 glazings. Included are the latest high-technology windows, such as those with low-emissivity coatings and gas fills to reduce heat loss. Also included is a set of experimental electrochromic glazings. The library was created using the WINDOW 4.0 computer program in a collaborative effort with the Windows and Daylighting Group. In addition, the WINDOW 4.0 glazing heat transfer model was integrated into DOE-2, yielding a more accurate calculation of conduction and solar gain through windows.

Other features in DOE-2.1E include add-on desiccant cooling, heat pump water heaters, new air-side and water-side economizer options, new heat pump defrost options, packaged variable-volume variable-temperature system, residential multizone variable-volume variable-temperature system, variable-speed electric heat pumps, gas heat pumps, a new water-source heat pump model, evaporatively cooled condensers, end-use metering, and an enhanced economics program.

In 1993 DOE-2.1E will be completd and released to the public.

Simulation Problem Analysis and Research Kernel (SPARK)

SPARK allows users to quickly build models of complex physical systems by linking calculation modules from a library. SPARK is aimed at simulation experts who need to create detailed models of building components and systems to aid in research and analysis of innovative technologies.

In 1992, the "strong component" feature was added to SPARK; this reduces solution time by decomposing large problems into smaller ones. Work continued on the SPARK interactive editor with which users graphically assemble networks that represent the physical problem to be solved (Fig. 1). Enhancements were made to the SPARK/Macsyma interface, which allows users to express calculation modules in mathematical notation, thus relieving users from having to write and debug computer code.

In 1993 a beta-test version of SPARK will be released to selected outside users after completing the graphical user interface, expanding the library of calculation objects, and writing of user documentation.

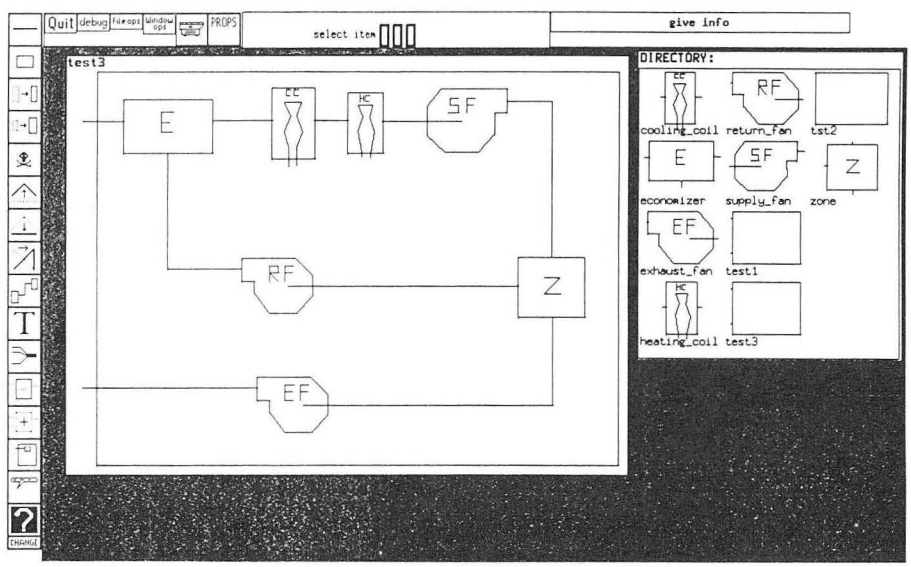

Figure 1.

Sample screen from the SPARK interactive graphical editor. Two windows are shown: "DIRECTORY" is an excerpt from the library of calculation modules ("objects") in which icons represent fans, coils, etc.; "test3" is an HVAC system network configured by the user by connecting objects selected from the library. The menu bar along the left side of the screen allows the user to select, move, connect, and delete objects.

DOE-EPRI Program

The DOE-EPRI program is under joint development by the Simulation Research Group and Hirsch & Associates, with support from the Department of Energy and the Electric Power Research Institute. It is a major extension of DOE-2 that is easier to use, provides built-in design guidance, and, by incorporating SPARK techniques, allows models for new HVAC technologies to be quickly built up from component modules. This program is aimed at a broad range of users: the average architect/engineer, for rapid design of energy-efficient buildings; researchers, for impact analysis of new technologies and development of future energy standards; and utilities, for support of demand-side management and marketing efforts.

The tasks in this three-year effort include:

- Improve the DOE-2 calculation engine: integrate SPARK and its object library into DOE-2 to simplify modeling of new technologies; combine the Loads, Systems, and Plant calculation into a single time step; add library of system controller functions; upgrade coil and compressor models; improve HVAC sizing methodology; enhance output reports and options.
- Develop a new user interface that is interactive and menu-driven; satisfies different levels of user proficiency, novice to expert; provides on-line help and graphical results display; accesses library of buildings, spaces, schedules, and HVAC configurations; can automatically generate building description from type, vintage, area, number of floors, etc.; and communicates with the Energy Design Advisor.
- Develop the Energy Design Advisor, which provides expert-system modules for design guidance. This is being done by the LBL Windows and Daylighting Group.
- Connect to CAD: develop an interface to popular CAD packages, such as AutoCAD, in order to simplify accurate architectural description of buildings.
- Provide enhanced program support in order to handle the greatly increased number of users that is anticipated. Support will include program maintenance, newsletter, training courses, hot line, electronic bulletin board, referral to modeling consultants, and documentation maintenance.

In 1992, we began the design and implementation of the user interface.

Development of the DOE-EPRI program will continue in 1993, with emphasis on developing the user interface, restructuring the basic DOE-2 simulation code to permit interaction with the user interface, combining Loads/Systems/Plant calculations into a single time step, and developing a connection to spreadsheet programs for display of simulation results. Release of Phase I of the DOE-EPRI program is expected in late 1993 or early 1994.

Retrofit Energy Savings Estimation Model (RESEM)

We developed the building-specific Retrofit Energy Savings Estimation Model (RESEM) for the DOE Institutional Conservation Program (ICP) in order to improve the quality of savings estimates. For maximum accuracy and validity, pre-and post-retrofit energy use—and thus savings—are directly based on utility billing data. RESEM is a user-friendly tool that allows state and regional ICP staff to use readily available information to determine the energy and cost savings due to ICP-supported retrofits for a single building.

Highlights of the operational computer tool include the user interface, which uses dynamic menus and pop-up windows for specialized data entry. The overall menu structure is designed to lead the user easily through the complex savings analysis sequence. Built-in simulation capabilities used in the analysis are transparent to the user and quite fast (less than 5 seconds on a 386-class PC) to simulate a typical building. Additional automatic features such as complete-default building generation and "push-button" retrofit descriptions have worked quite well in early use experience, saving the user time and effort in describing the buildings and the retrofit measures.

In 1988 and 1989, we designed and implemented most of the tool, yielding an operational prototype. In 1990 we completed the primary software implementation of the tool, and initiated field testing and documentation. A limited beta-test was carried out using several State energy and DOE operations offices. In 1991, final RESEM software development and an accompanying Reference Manual was finished, incorporating feedback from early user experience. Work on an extensive weather data library covering in excess of 200 locations was also completed.

Since then, product announcements and presentations were made to introduce RESEM to potential end users, and numerous demonstrations of RESEM have been made to ICP and other DOE program managers, as well as other interested parties. Several technical papers describing the capabilities and methods used in RESEM have been published and presented.

Energy Design Tool for Small Commercial Buildings

A DOE-funded industry/laboratory collaboration between the Passive Solar Industries Council (PSIC) and the National Renewable Energy Laboratory (NREL) was initiated in 1990 to develop design guidelines for energy-efficient small commercial and institutional buildings. A key element of this project is the development of a computerized tool which provides an interactive environment in which to explore the energy impacts of various building design decisions. LBL is providing technical support in the development of this design tool.

The design tool is being developed to operate on an IBM-compatible PC under the MS-DOS and Windows operating system. This tool is meant to go well beyond the type of energy evaluation programs which are currently available. Innovative features include the initial generation of a complete building simulation model from minimal input data, intuitive access to and modification of the design details of the building, intelligent guidance in the selection and specification of energy-efficient measures for improving the overall performance of a building, and a variety of criteria for evaluating the relative performance of alternative building designs. An especially critical aspect of the tool is the user interface which provides access to the inherently complex details and tasks related to building design.

In 1991 LBL provided support during early design tool planning in the selection of the tool's hardware platform and software development environment and programming tools. Initial efforts focused on the importance of the tool's user interface, implementing the first functional prototype of an interface specified by NREL for use as a demonstration for the project sponsors (Figure). In 1992, LBL provided capabilities for describing, and algorithms for evaluating, a basic set of simple energy-efficient daylighting strategies (vertical glazing and skylights). We also began to explore a number of approaches for describing and evaluating more complex and varied daylighting strategies. These capabilities are planned for implementation in 1993.

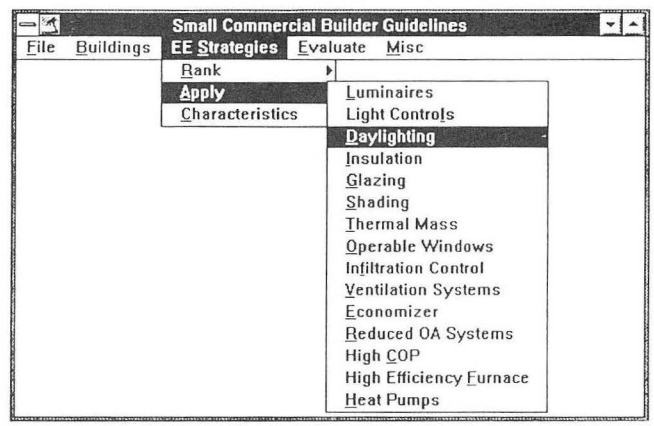

Figure 2.

Pull-down menu selection from small commercial builder guideline tool for applying a daylighting strategy to the current building design.

Reference

Nataf JM, Winkelmann F. *Automatic Code Generation in SPARK: Applications of Computer Algebra and Compiler-Compilers.* Lawrence Berkeley Laboratory Report No. LBL-32815, 1992.

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