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Windows & Daylighting
A Brighter Outlook . . .

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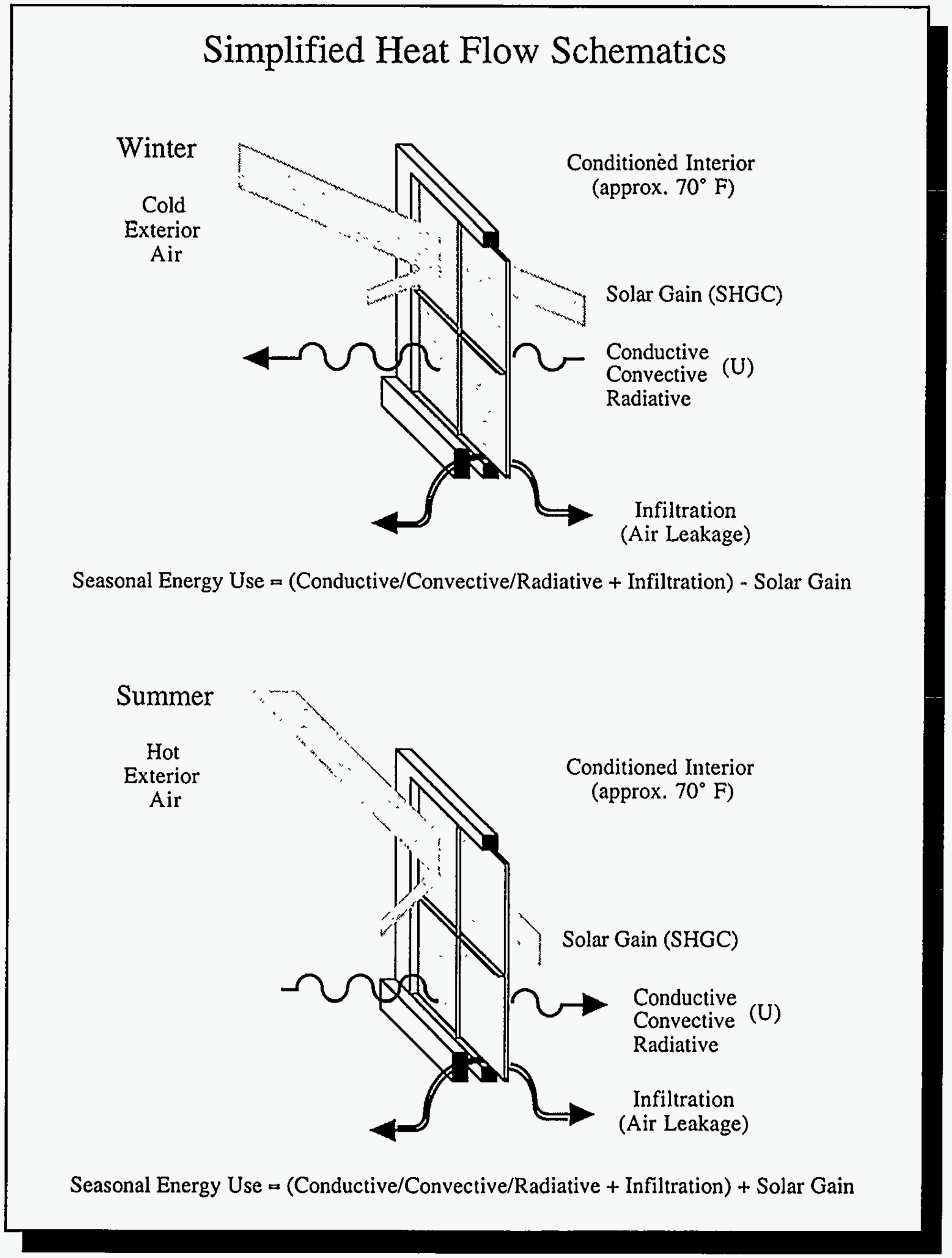
Windows and Energy Use, A Point of View

$20,000,000,000! That is the estimated value of the energy lost through the windows of the buildings in this nation in 1993. In fact, unwanted heat gain and loss through windows represents over five percent of total U.S. annual energy use. While windows may impose energy penalties on buildings, they provide other important contributions to buildings and their occupants. In their earliest applications, windows provided an outlet for smoke from cooking and heating fires, an inlet for fresh air, and a source of daylighting for an otherwise dark interior. Since the development of clear glass some 2,000 years ago, windows have evolved into the single most outwardly expressive component of residential and commercial building architecture. In addition to their use as a source of daylighting and ventilation, today window systems establish the exterior and interior aesthetics of buildings. More importantly, they provide occupants with a vital link to the outside world, a source of information regarding their surroundings, and they play an important role in the psychological well-being and productivity of the occupants.

Energy transmitted through windows is generally categorized as:

(1) Solar radiation (e.g., visible light and heat gain from the sun) that passes directly through glass into a building structure;
(2) Non-solar heat flow in the form of conduction (the flow of heat through a material), convection (heat transfer involving motion in a fluid caused by the difference in density and the action of gravity), and low temperature radiation (e.g., heat radiated from a human body or a room to the night sky);
(3) Air flow, both intentional (ventilation) and unintentional (infiltration) that carries heat into and out of a building.

With modern architectural practices, new materials, and high strength fastening techniques, all-glass commercial building exteriors are now a common skyline feature. In the residential sector, the percentage of glass area in a typical house has increased by 25 percent over the past 20 years. Fortunately, technical advances that have allowed an increase in the application of windows have been applied to the energy performance of these products as well. Once-common single pane windows have given way to predominately double pane windows, and even triple pane units in very cold climates. Within the past five years, windows with energy saving coatings and films have been developed and have made substantial inroads into the residential market. When combined with new frame designs, these windows are more than three times as energy efficient as single pane units.

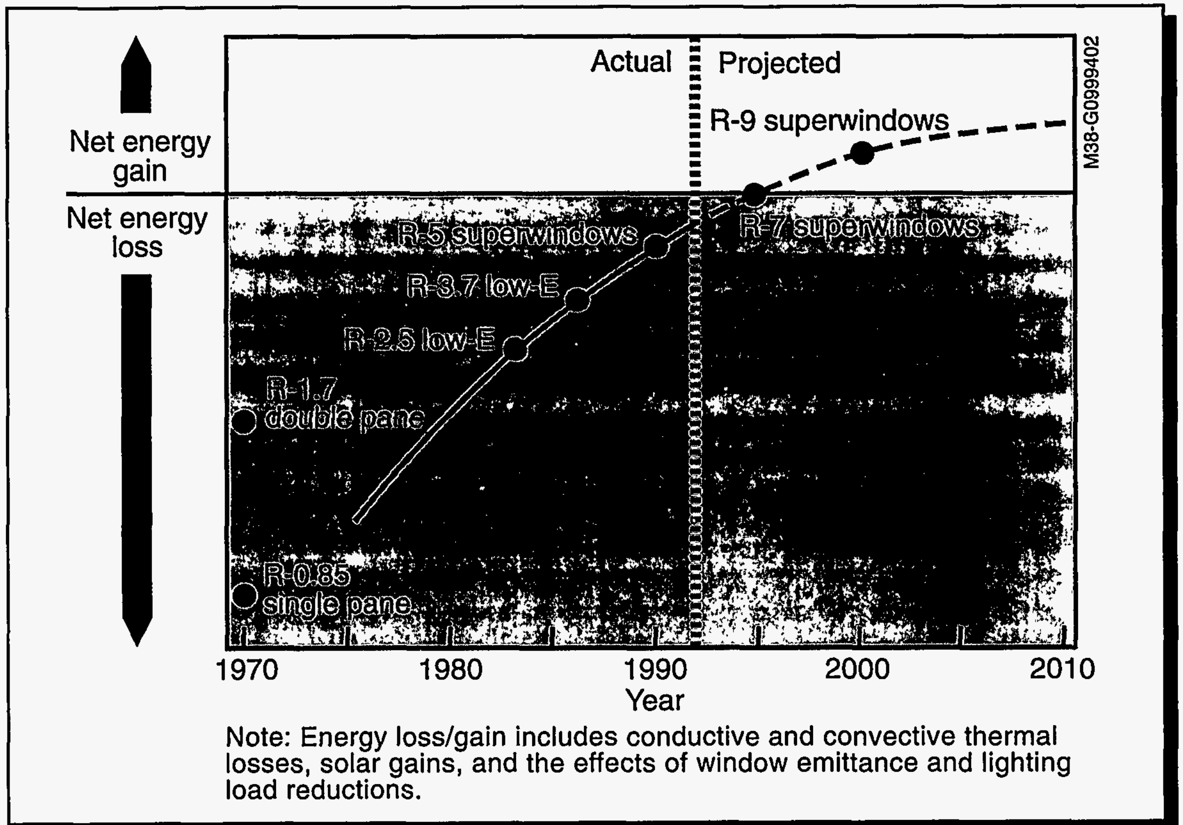


Simplified Heat Flow Schematics

A Challenging Federal Opportunity

As substantial as the improvement in window energy performance has been in recent years, there is still an opportunity for further gains. Research shows that windows could be made to restrict unwanted energy gains and losses as well as the best insulated building walls. Windows of the future may well become energy providers to buildings through the selective capture of solar radiation, variable reflectance and thermal transmittance capabilities, and displacement of electrical lighting with natural daylighting techniques.

The research and development required to produce the next generations of energy efficient windows is of a high risk nature, representing many years of incremental improvements in materials, technologies, and design approaches. And while industry is proceeding cautiously along this path of product improvement in response to market forces, the potential for significant energy savings coupled with the high risk nature of the required R&D presents an opportunity for the federal government to accelerate the delivery of substantial energy benefits to the U.S. public.



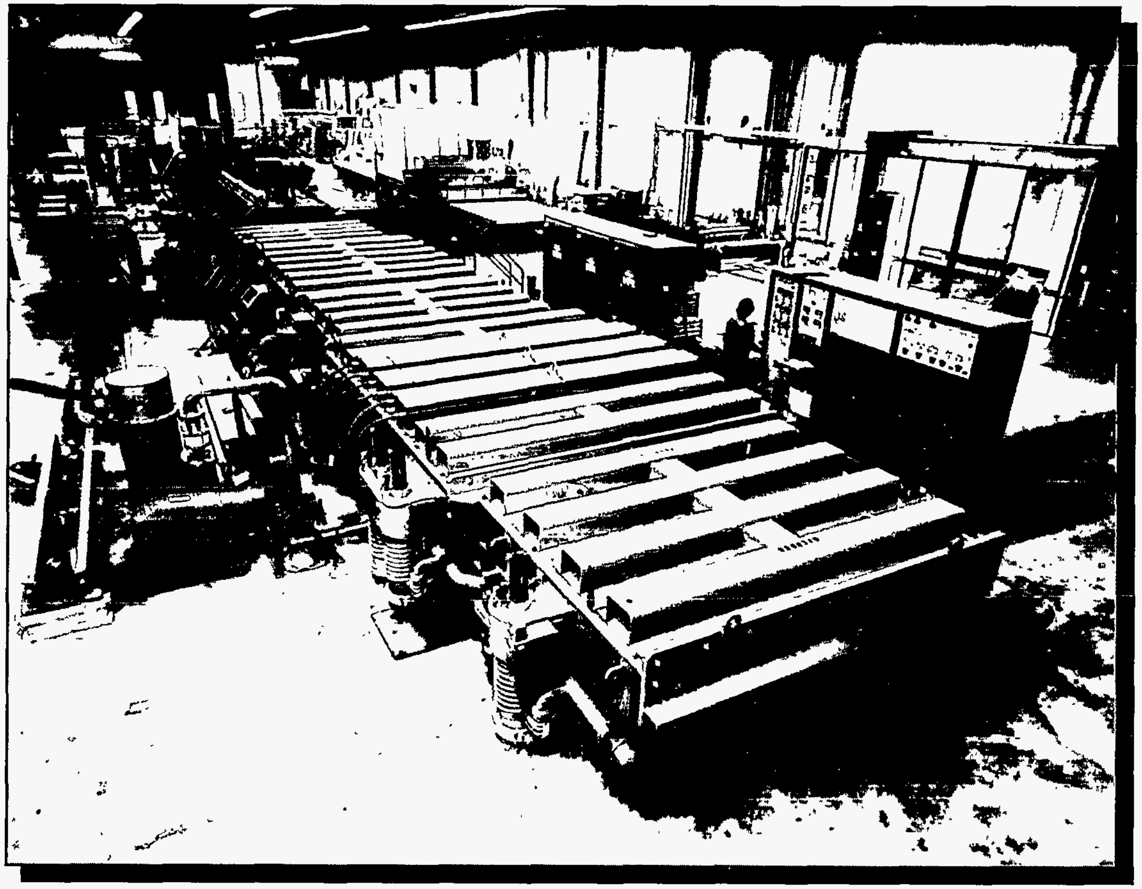
Windows - Annual Heating Energy Use Per Window in Typical Northern Heating Climate

The U.S. Department of Energy (DOE), has recognized this opportunity and has played an important role in the development of a number of advancements in window technology including reflective and low-emissivity coatings, insulating gas fills, and design concepts that optimize the use of daylighting. It is estimated that the approximately $20 million of federal investment over the past 10 years in research related to windows and the effective use of daylighting has yielded well over one billion dollars worth of energy savings to consumers. It has also stimulated the window industry into recognizing that value-added features such as energy performance are attractive to consumers.

Low-Emissivity Coatings—"A DOE Success Story"

In the late 1970s, DOE's window research program at the Lawrence Berkeley Laboratory (LBL) set out to develop a window coating that would appear transparent to visible light (short wave radiation) but would reflect heat (long wave radiation). Selective transmittance and reflectance capabilities could reduce unwanted heat gain and loss through a typical double pane window by up to 50 percent. While the concept of such a low-emissivity (Low-E) coating was understood at the time, most window manufacturers placed a low priority on the technology and its potential for energy savings.

LBL began a series of research projects with several small firms aimed at developing optimal coating materials, and the process technologies required to economically apply these coatings to glass and plastic films. By 1981, one of these firms, Southwall Technologies, began producing a first-generation, low-E window, and was working with several larger window manufacturers to further refine the product for their use. A major installation of glass coating process equipment in 1983 signalled the first commitment by a large U.S. window manufacturer to offer low-E products for the residential building industry. By 1986, more than 20 manufacturers were marketing low-E windows, and by 1993 about one-third of residential and one-fifth of commercial window sales employed low-E coatings.



A Modern Industrial Glass Coating Facility

DOE Window Research

The long-term goal of the Department of Energy window research program is to convert windows, doors, and skylights into energy assets rather than energy liabilities, while maintaining or improving the comfort, health, and amenity that these features provide to buildings and their occupants. Towards achieving this goal, the following objectives are addressed:

Minimizing undesired heat losses and gains. How a window impacts building energy use is a function of both its direct energy performance and numerous other variables such as climate, building type and orientation, and building application; with no single set of characteristics providing optimal performance for all conditions. A number of different approaches must therefore be developed to accommodate the many variables, and combinations of variables, contributing to overall building heat gain and loss through windows.

Maximizing the effective use of daylight. Electric lighting imposes two energy demands on buildings: (1) the electrical energy required to produce the lighting itself; and (2) any cooling energy that is required to offset the heat produced by lighting elements and their associated electronics (ballast) and controls. Replacing electric lighting with natural daylighting has the potential for substantial energy savings, provided that unwanted heat gains and losses through the sources of daylighting can also be minimized.

Implementing ratings on labeling systems. In addition to the above, a major program objective is to greatly improve the responsiveness of users and window producers towards adoption of energy efficient window technologies. The marketplace requires accurate information about the performance of window products. The complexity of energy flows in windows needs to be simplified into a system of ratings and labels. DOE is conducting significant research to assure the credibility and effectiveness of the rating system now being implemented by the National Fenestration Rating Council (NFRC). In addition to providing for better *metrics*, this research provides for the development of guidelines and design tools to stimulate demand and to assist producers in producing better products.

These objectives are addressed by a broad range of federally-supported activities that includes both fundamental and applied research, manufacturing technology development, creation of design tools, and technology transfer.

Advanced Optical Technologies;

Opportunities For High Performance Window Products

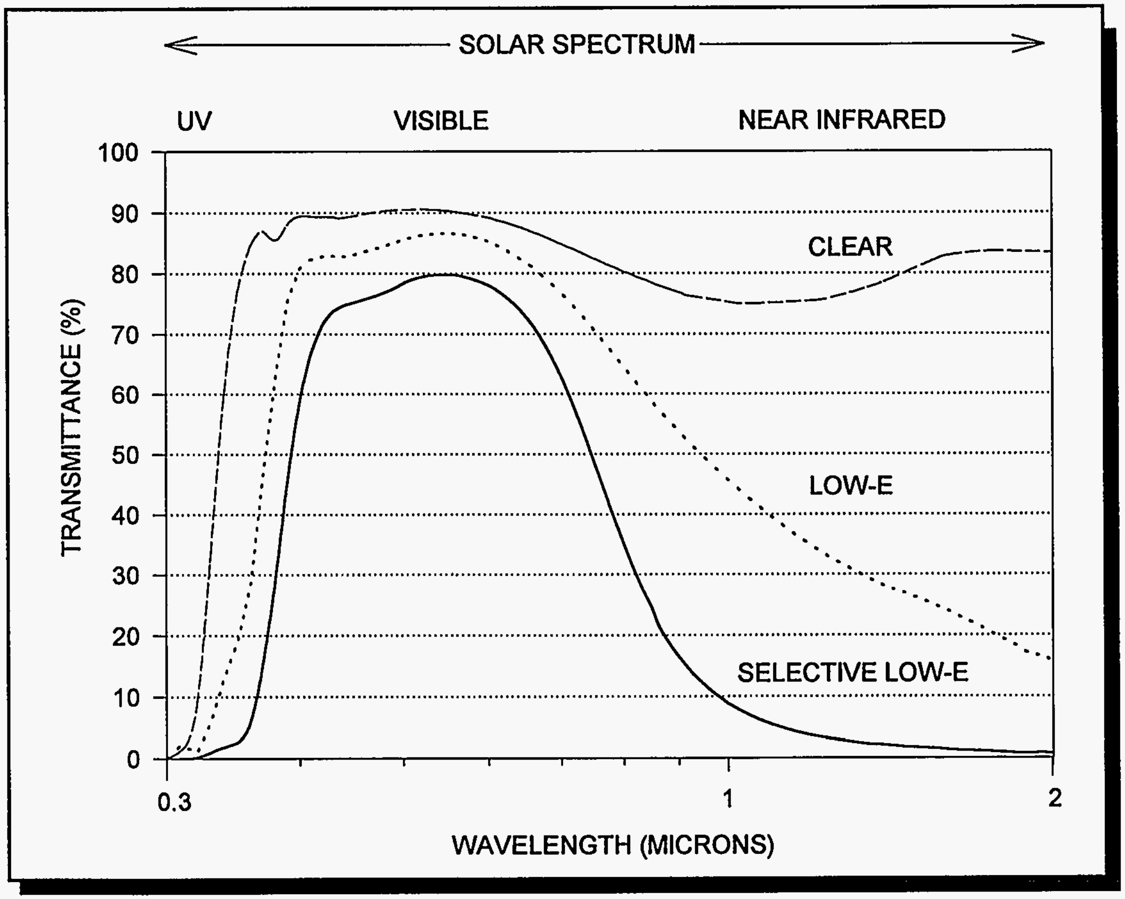
The product mix of the window industry of today reflects a number of innovations designed to improve the energy performance, optical clarity, and aesthetics of residential and commercial windows. Low-E coatings, tints, reflective films and coatings, gas fills, and new frame materials and designs are features that offer substantial energy savings to consumers, and opportunities for window manufacturers to add value to their product line at a time of increased energy and environmental awareness.

While a good window today is almost twice as energy efficient as the standard double glazed units of the early 80s, most of the energy saving potential for advanced windows has yet to be captured. Researchers are working to further improve on current technologies, expand high performance window applications to retrofit markets, and ultimately turn windows into dynamic energy supply systems that continuously respond to the energy and daylighting needs of buildings and their occupants.

"Cool Windows" Using Selective Glazings

Window glass and plastic films can be coated with microscopically thin metallic layers or incorporate tints that reflect or absorb some or all of the wavelengths of the solar energy spectrum. A desirable "selective glazing" would allow solar energy wavelengths in the visible spectrum (daylight) to pass through a window while reflecting near infrared (heat) and ultraviolet (fabric damaging) wavelengths. Reflective coatings do a better job of reflecting the sun's energy than absorbing glazings. These "cool windows" reduce cooling loads by up to 50% but still look clear to the human eye.

First generation selective coatings have already been used successfully by several glazing manufacturers in products aimed at commercial and sunbelt residential applications. These high performance silver-based coatings require protection within a sealed glazing assembly to avoid degradation. DOE is supporting development of new materials and associated manufacturing processes that produce harder, more durable coatings which maintain the optical properties necessary for both energy performance and visual clarity. Researchers have achieved success in producing highly durable selective glass in small sample sizes and are now perfecting the coating process. It is anticipated that within a few years, this new generation of selective coatings will be available for use on exposed surfaces including removable-sash windows and add-on retrofit products, all of which represent a substantial portion of the residential window market.

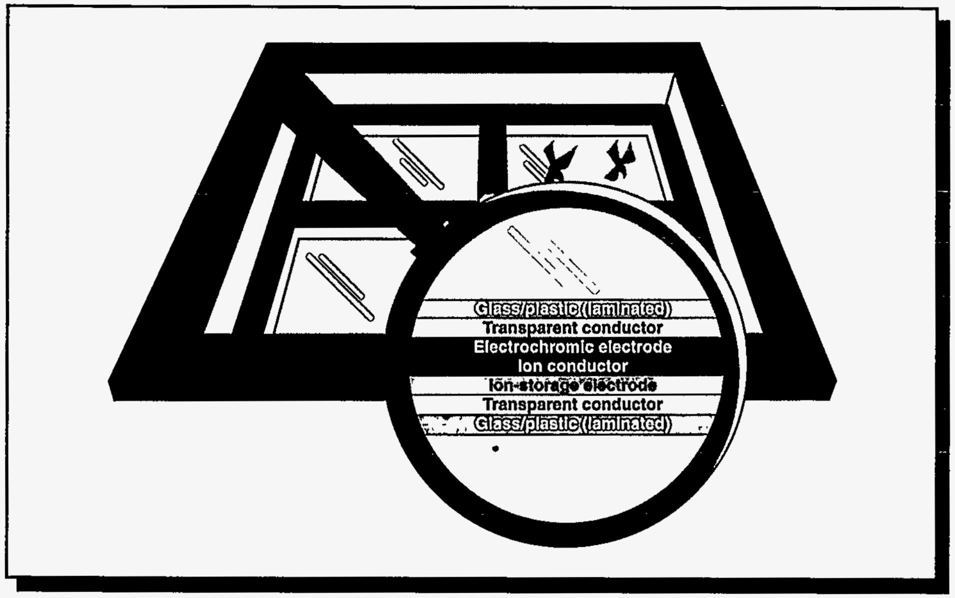


Effectiveness of Low E Coatings in screening out the unwanted (Ultra violet and near Infra-red) wavelengths of the solar energy spectrum

"Smart Windows" with Switchable Glazing

The next technological step beyond selective glazing is the capability to dynamically alter the solar-optical properties of a window. A switchable glazing can change its properties upon some external stimulus. Some types of switchable glazings respond directly to an environmental variable such as heat or light. A more controllable, and thus more desirable type is a glazing whose properties are altered via a low voltage electrical signal. Building occupants could control heat and light transmitted through the windows by simply adjusting a switch.

Some switchable glazings have been around for years. For example, photochromic glass that darkens in bright light is common in sunglasses but is not yet available in large sheets for windows. Several new switchable products are becoming available. One is a combination photochromic and heat-sensitive thermochromic material intended largely for skylights. When its temperature rises, this material changes from clear to a reflective milky white to block heat gain from the sun. Another newly introduced product uses a thin layer of liquid crystals sandwiched between glass. It is clear when electricity is applied and diffusing when the power is off. This product is meant more for diffusing sunlight and for privacy applications and has only limited ability to control cooling loads from the sun.



Electrochromic "SMART" Window

The most promising of all switchable technologies are electrochromics, and this is where DOE has focused its smart windows research. An electrochromic coating typically is a five layer coating in which a small applied voltage moves electrical charges between layers causing changes in both color energy flow. The transmittance of electrochromic glazings is continuously controllable over a wide range from clear to dark. The voltage signal that controls the coating can either be directly initiated by building occupants or can be linked into an automated building climate control or security system.

DOE past materials research efforts have developed prototype coatings with promising performance properties. In order to accelerate development and move this technology more rapidly to commercialization DOE is now conducting a new cost-shared partnership with industry. The goal is to produce large prototype electrochromic samples for performance testing and to develop low cost production process technology. Within three to five years, it is anticipated that electrochromic glazing will be ready for market introduction.

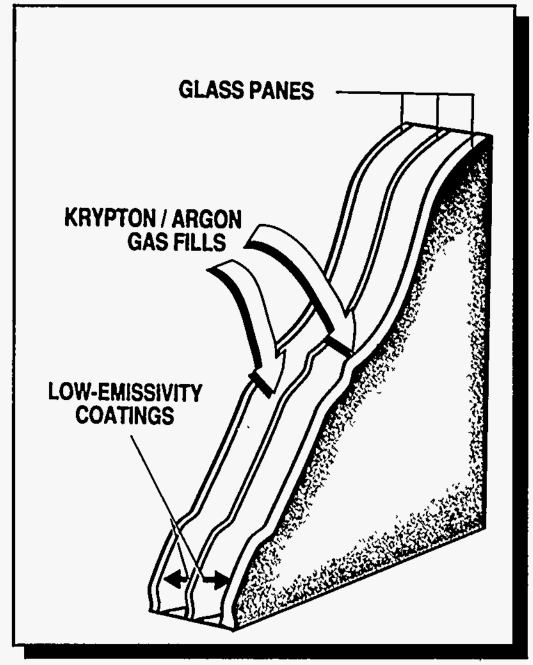
Super-Windows

A superwindow is a highly insulating window with a heat loss so low that it performs better than an insulated wall in winter, since the sunlight that it admits is greater than its heat loss over a 24 hour period. Superwindow research focuses on the design, development and testing of new windows and window components such as frames and edge seals, and on new materials and techniques to reduce thermal losses across window systems. An objective of the research is marketable window products with insulating values up to five times as high as conventional double glazed windows. Another objective is for the vast majority of window manufacturers to incorporate several of these technologies into their windows. The increased availability of very high-R windows plus incremental improvements in the mainstream windows would effect a shift in average performance from less than R-2 to over R-5, and result in significant energy savings.

Begun in the late 1980s, this R&D project has already led to the commercialization of first-generation superwindows utilizing multiple low-E coated glazings with inert gas fills, and improved edge spacers. These windows advertise a center-of-glass R-value of 8, with an overall window R-value of about 5.

The next generation of superwindows will likely incorporate the results of cooperative industry and DOE research to further improve the glass edge and to reduce losses through the sash and frame. Glazing improvements will result in lower heat loss and improved optical properties, such as evacuated air spaces and regionally optimized optical properties.

Field testing of superwindows has demonstrated that these windows deliver on their promises. DOE used its Mobile Window Thermo Test (MoWiTT) facility to test and compare superwindows against an insulated wall panel and showed that over a period of cold, cloudy weather that the windows lost less heat than an insulated wall. Computer simulations show that even when installed in north facing walls, these superwindows will outperform an R-50 wall system on a yearly basis, since the superwindow takes advantage of solar energy gain to offset the heating requirements of buildings during winter days. And the first utility sponsored field test of superwindows in 100 houses provided an average reduction of 25% in winter heating bills.



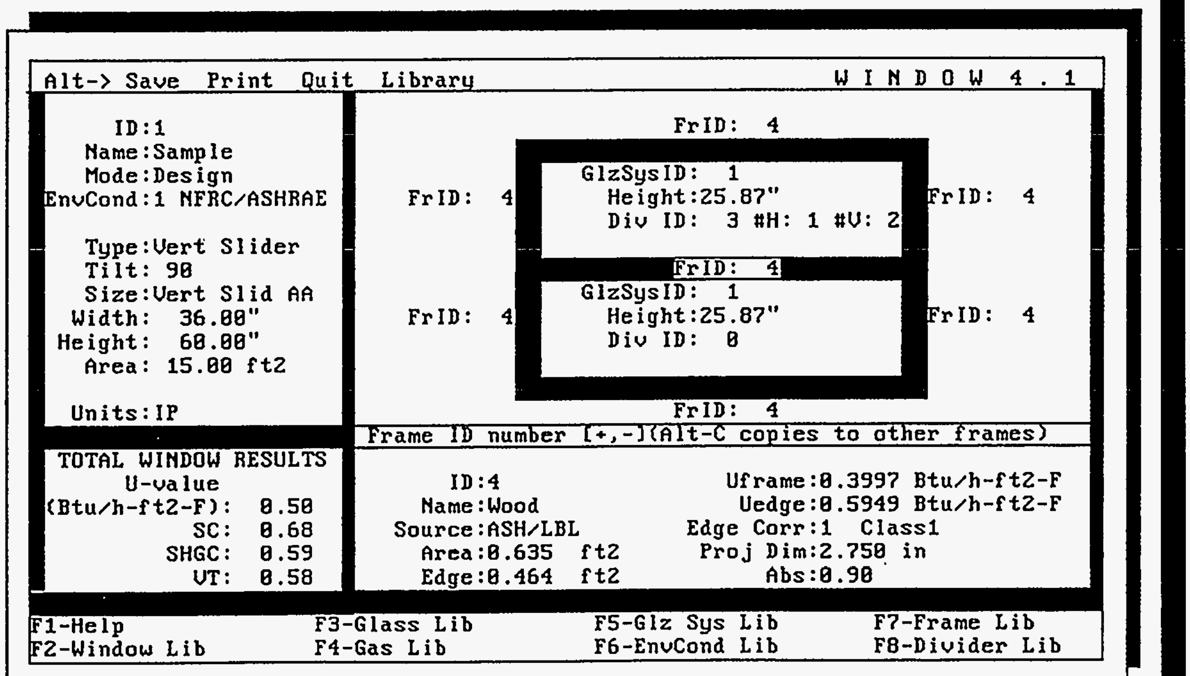
Cross Section of an Energy Efficient Window

Performance Evaluation and Design Tools Forming a Basis for Window Development and Application

Residential and commercial building windows are exposed to a wide range of variables including changes in weather, seasonal cycles, geographic location, architectural placement, and building use patterns. It is important to be able to accurately characterize the effects of these variables on the daylighting and energy performance of windows, and to translate this information into useful products for window manufacturers, architects, and consumers. DOE researchers are continually working on several fronts to provide analytical models and design tools for use in window performance analysis, testing facilities to verify both analytical tools and actual window system designs, and technical expertise in support of private industry efforts to improve the energy performance of window products and their integration into building design.

Analytical Models

The growing numbers of new window coatings, insulating gas fills, and frame designs being developed for window applications have made window energy performance calculations a highly complex task. DOE has developed, and continues to update, a number of computer-based analysis programs to aid window manufacturers and building designers in optimizing the energy and daylighting performance of window systems. The DOE WINDOW program, for example, predicts the performance properties of most window designs and has become a standard tool in the window and glazing industry. Similar computer-based tools are being developed to improve



Main Screen from WINDOW 4.1 Program

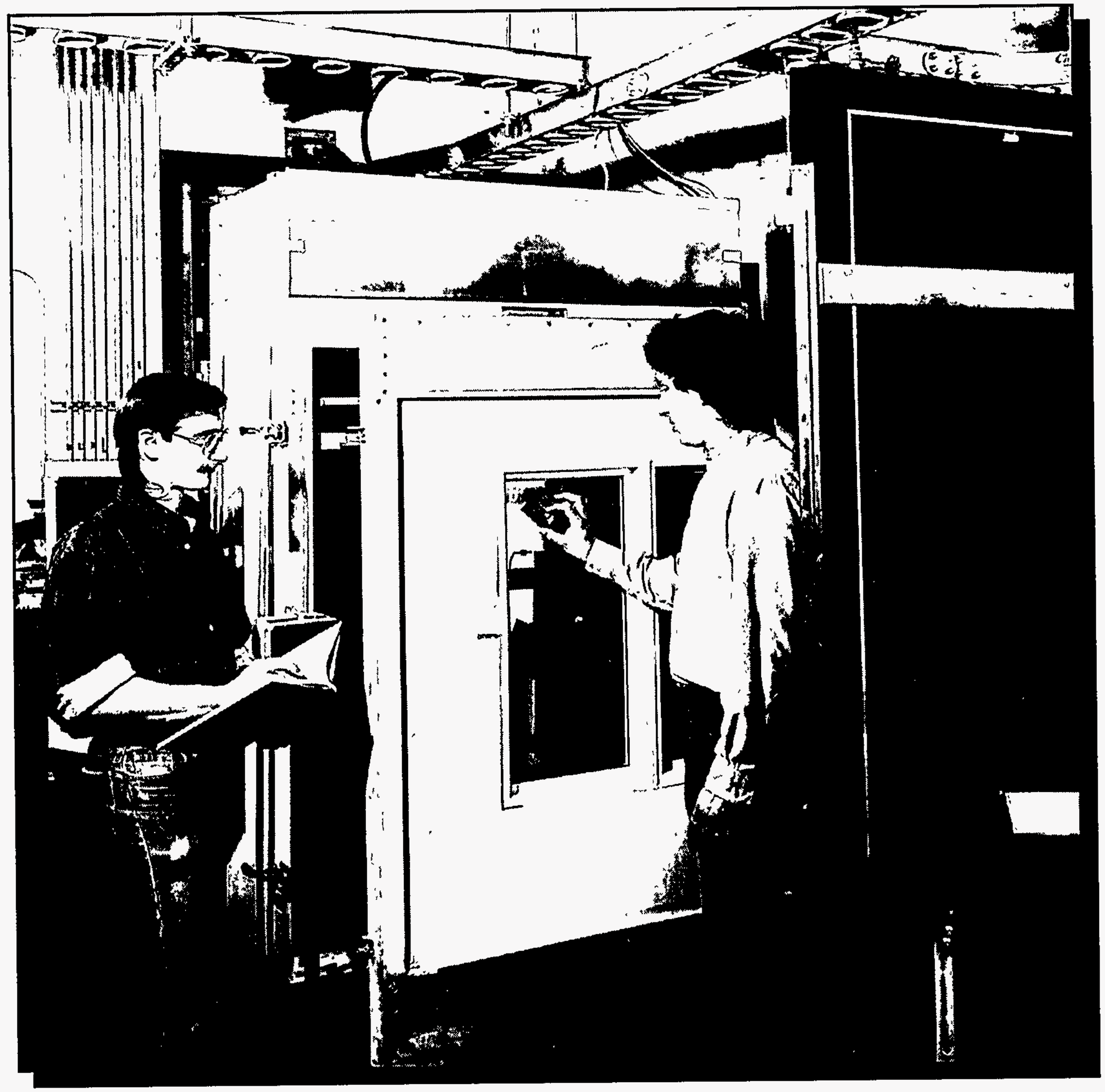
the capability of window manufacturers and architects to determine solar heat gain and solar-optical properties of complex window systems and commercial building curtain walls.

Window Performance Testing

DOE has developed and operates testing facilities that provide both private industry and federal researchers with an opportunity to verify the actual performance of window systems against both analytical modeling predictions and manufacturers' product designs.

These facilities include, for example, the infra-red thermography and the mobile window thermal test facilities described below. They also include a durability test facility at NREL and thermal test chambers at ORNL.

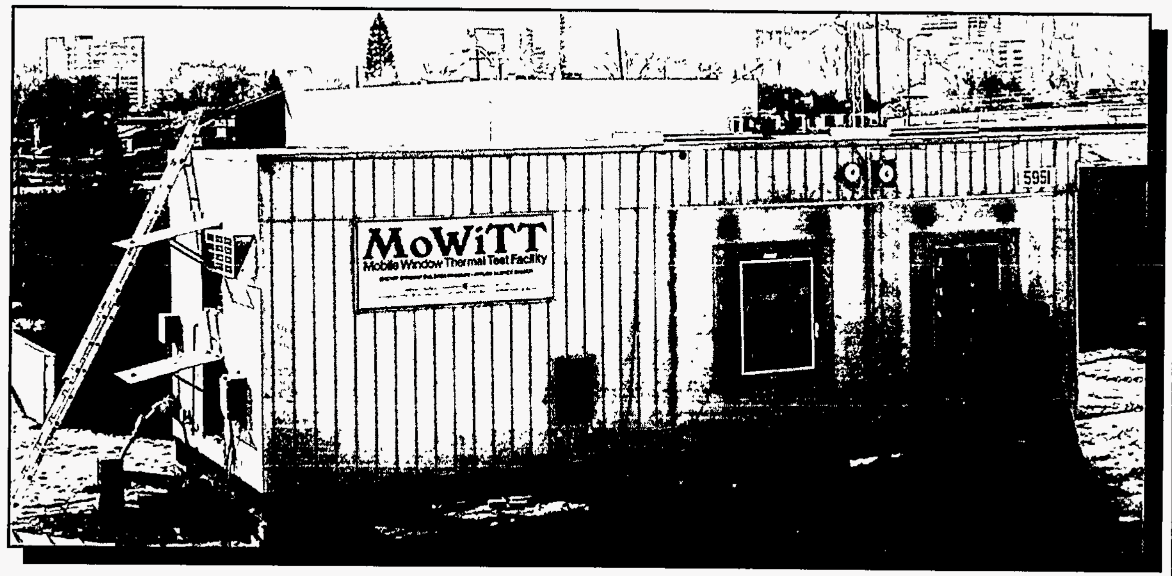
The infrared thermography facility located at the Lawrence Berkeley Laboratory allows precise measurements to be made of differential temperatures across window and frame surfaces.



Thermograph Facility

Window Performance Testing (continued)

The Mobile Window Thermal Test (MoWiTT) facility allows windows to be tested under actual ambient conditions. As designated "user facilities," the MoWiTT and the other test facilities addressed here are available for private industry use at the DOE cost for operating them.



MoWiTT

Window Energy Ratings

Concern about the energy performance of windows has prompted several states to introduce legislation requiring energy rating and labeling of window products. Realizing the benefits to both consumers and manufacturers that a nationally acceptable window energy rating system would provide, a consortium comprised of industry, trade associations, utilities, and public interest groups established the National Fenestration Rating Council (NFRC) in late 1989. The mission of the NFRC is to establish a fair, accurate, and credible rating system for fenestration product performance and to coordinate certification and labeling activities to ensure their uniform application.

NFRC's window energy rating and labeling system is now recognized by several state energy code bodies, and the recently published second edition of its Certified Products Directory provides energy performance listings for over 5,000 windows, doors and skylights.

CERTIFIED National Fenestration Rating Council

AAA Window Company

Manufacturer stipulates that these ratings were determined in accordance with NFRC 100-91.SM

U-value	AA	5' x 3'	0.40	Model #1500 Horizontal Slider
U-value	BB	6' x 4'	0.38	0.5" Air Space, Low-e 0.2

NFRC ratings are determined for a fixed set of environmental conditions and may not be appropriate for determining seasonal energy performance. For additional information contact: NFRC, 1300 Spring Street, Suite 120, Silver Spring, MD 20910; Tel: (301) 589-NFRC, Fax: (301) 588-0854.

NFRC Window Energy Performance Label

DOE has been an important partner to NFRC by assisting in the development of the technical basis for many of NFRC's rating procedures. Federal support for window energy rating activities included the continued updating of the DOE-developed WINDOW computer program which was adopted by the NFRC as its method of determining window performance properties.

Research is conducted largely through LBL, the program's lead laboratory. Other DOE-funded research is conducted through the National Renewable Energy Laboratory, the Florida Solar Energy Center, the University of Massachusetts, and others, and through close collaboration with industry and Canadian and foreign research organizations. This research and testing will form the basis for the establishment of the NFRC energy rating procedures. The product of this effort will be a simple rating number on a window label that will assist the consumer in selecting more energy efficient products.

Looking to the Future

Window and daylighting technologies now entering the marketplace or in the advanced stages of development will undoubtedly impact the way in which windows will be applied in both new construction and retrofit actions over the next 20 years. Since these products and design strategies will facilitate the use of natural daylight to the maximum extent possible without incurring unwanted energy gains or losses, the amount of glass area employed in building walls and roofs will increase substantially. Increased use of window and daylighting technology will in-turn produce new concepts in both exterior and interior building architecture, changing the way in which interior space is used, and minimizing the impacts of buildings on the external environment as well through reductions in "heat island" effects and reduced need to burn fossil fuels.

In projecting even farther out into the future, research is already underway on the next generation of optimum window systems; building envelopes capable of providing all requirements for daylighting, heating, and cooling, and electrical loads with optically efficient, super-insulated, photo-voltaic glazing. Windows may also be equipped with holographic capabilities for projecting information and lighting throughout building interiors.

Drawing of a Future Building

Window Research Information

Federally sponsored window and daylighting research is managed by the Office of Building Technologies, U.S. Department of Energy headquartered in Washington, D.C. The Lawrence Berkeley Laboratory at the University of California conducts program research with the Florida Solar Energy Center, and the National Renewable Energy Laboratory. The University of Massachusetts and other universities, government, industry consortia in collaboration with Canadian foreign research activities participate in selected projects.

Private sector participation is an important component in all phases of DOE window research. Representatives from the manufacturing sector, the building design and construction industry, utilities, and consumer organizations all play an active role in shaping the content and direction of the program during annual planning exercises and peer reviews of ongoing R&D. The most important aspect of private sector involvement, however, consists of industry and utility participation in, and cost-sharing of, a large percentage of the development and demonstration efforts necessary to establish the commercial viability of DOE-developed technologies.

Selected Publications

"Amazing Glazing," Progressive Architecture, July 1994.

"Consumer Guide to Energy Saving Windows," Jeffrey L. Warner, Home Energy, Vol. 7, No. 4, July/August 1990.

"Technics: Windows to the Future," Progressive Architecture, June 1990, p. 47.

"Certified Products Directory", National Fenestration Rating Council, August 1994

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