American Energy Innovation Council

CASE STUDIES ON THE GOVERNMENT'S ROLE IN ENERGY TECHNOLOGY INNOVATION

Low-Emissivity Windows

By Jeffrey Rissman and Hallie Kennan | March 2013

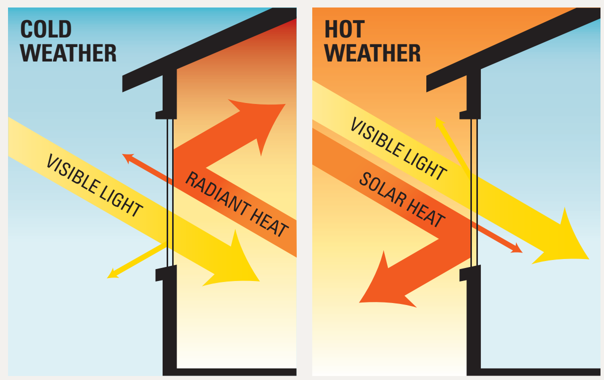
Introduction

Improving the efficiency of buildings is one of the most promising ways for the United States to bolster the economy, improve public health, and protect the environment. Buildings account for 41% of total U.S. energy use, more than any other sector.[1] This energy comes at a steep price. The 40 quads of energy consumed by buildings each year cost $418 billion, and three fourths of that energy comes from natural gas, coal, and petroleum.[2] As a result, buildings' energy consumption accounts for 39% of all carbon dioxide emissions in the U.S.,[3] as well as other air pollutants that have been linked to cardiovascular disease, respiratory disease, and premature death.[4, 5, 6]

Typical commercial buildings waste 30% of the energy they consume, mostly by heat and cooling loss through the building envelope (windows, doors, roof, etc.).[7] Losses through windows alone are estimated to cost U.S. consumers roughly $40 billion each year.[8] Efficiency upgrades that prevent this loss are among the most promising and cost-effective energy technology options now available. A National Academy of Sciences study, which analyzed the costs and benefits of a host of DOE-supported renewable energy and energy efficiency innovations, singled out building energy efficiency (and one fossil energy program) for praise. The study concluded that, "by an order of magnitude, the largest apparent benefits [of the technologies examined] were realized as avoided energy costs in the buildings sector in energy efficiency."[9]

One technology that has been a critical driver of building energy efficiency improvements in the last several decades is the low-emissivity (low-e) window. Low-e windows use insulated glass to reduce the amount of heat energy, or infrared radiation (IR), that is transmitted through the window.[10]

Figure 1: **Low-e windows transmit most visible light and block most infrared radiation (heat).**



How Low-e windows work

In the same way that light travels through a window to provide us with visibility, heat also permeates the glass, which can either enter into a building space (in a hot climate) or escape to the outside (in a cold climate). This concept is known as *transmittance*, which is simply the percentage of radiation that passes through a material.[11] A window will typically have different transmittance values for visible light and for heat.

Any energy that is not transmitted through the window is either reflected off the surface or absorbed into the glass. There are three ways that absorbed heat may penetrate the window: by conduction through the glass and frame, by convection of the air in the gap between the window panes, and by emission of infrared radiation.[12] A window's ***emissivity*** refers to the third of these effects: the window's tendency to radiate absorbed heat, which is one of the most important mechanisms by which heat is transferred through a window.[13] A low-e coating greatly reduces the emission of radiant heat, improving the window's thermal insulation. In this way, a low-e coating can help keep heat inside a house in cold weather and can keep heat outside a house in hot weather.

In addition to reducing the emission of radiant heat, low-e coatings designed for hot climates greatly reduce the transmission (and increase the reflection) of infrared solar radiation. Low-e coatings intended for cold climates allow more solar heat to penetrate, warming the building.

The most common type of low-e window uses two panes of glass, with a gap between them. A microscopically thin metal or metallic oxide coating is applied to one of the two inner surfaces (those facing the cavity between the panes). In higher-performance low-e windows, the air in the cavity is often replaced with an inert gas that has lower thermal conductivity than air (such as argon or krypton). Very high-performance low-e windows use three panes of glass, with two inert gas-filled cavities. Some of these windows use a single low-e coating, while the most insulating windows use one per cavity.[14] In addition to heat that penetrates the glass, some heat is lost around the edges of the glass and through the window frame. Thus, the total amount of heat that passes through the window depends on the number of glass panes, the type of gas that fills the cavities between the panes, the performance of the low-e coating(s), and the design and material of the window frame.

Low-emissivity windows have benefitted society greatly since they were introduced to market 30 years ago. Relative to a good quality, single-pane window,[15] a modern, double-pane low-e window can reduce heat loss by over 70%, and the best triple-pane low-e windows can reduce heat loss by 85%.[16] Replacing single-pane windows with ENERGY STAR qualified windows, which require heat losses to be reduced by 40%–70% depending on geography,[17] would save a typical home in the continental U.S. $150-$500 and prevent the emission of one to two tons of carbon dioxide every year,[18] along with reductions in other pollutants associated with energy consumption. Other benefits include reduced fading on interior fabrics[19] and the potential for increased natural lighting, as shades and curtains are no longer necessary to keep building interiors insulated.

The government has played an essential role in the development and market adoption of low-e windows. Federal support fell into four categories: research assistance and seed investments for early private-sector companies developing low-e coatings, the creation of computer modeling tools to aid in low-e window design, supporting the National Fenestration Rating Council's development of uniform testing procedures and ratings of window performance, and efforts to boost marketplace adoption by educating manufacturers (through targeted outreach) and consumers (via the ENERGY STAR program).

Development of the Technology

The OPEC oil embargo of 1973 was the initial impetus for the United States government to develop energy efficiency technologies. The price of oil rose from $4.75 per barrel ($24 per barrel in current dollars) to $37.42/barrel ($104 per barrel in current dollars) over the course of the 1970s.[20] At the same time, the price of coal nearly quadrupled, from $6.34 per short ton ($38 per short ton in current dollars) in 1970 to $23.75 per short ton ($75 per short ton in current dollars) in 1979.[21] These price increases had a significant impact on the building sector because of buildings' reliance on heating oil for furnaces and boilers and on coal for electricity. The resulting economic distress and concern over foreign nations' ability to harm the U.S. by withholding energy supplies motivated the government to initiate R&D programs to increase energy efficiency in the building sector.

The federal government provided basic research and seed investments to catalyze low-e technology development in the absence of private sector efforts.

The concept of low-emissivity coatings originated in the World War II era, but in the ensuing decades, no private firm had undertaken the research necessary to turn the concept into a commercial window product.[22] Even in the 1970s, when the need for efficiency technologies became acute, industry was "too concerned with rising fuel costs and with responding to building codes limiting window areas to put much effort into a speculative new technology," according to a report by Oak Ridge National Lab.[23] In 1976, the Energy Research and Development Administration (ERDA; now the Department of Energy) launched a window research program at Lawrence Berkeley National Lab (LBNL). The goal of the program was to understand the scientific mechanisms of heat transfer in windows and to identify technical opportunities for reducing those losses, ultimately paving the way for private firms to commercialize the technology and bring products to the marketplace.[24]

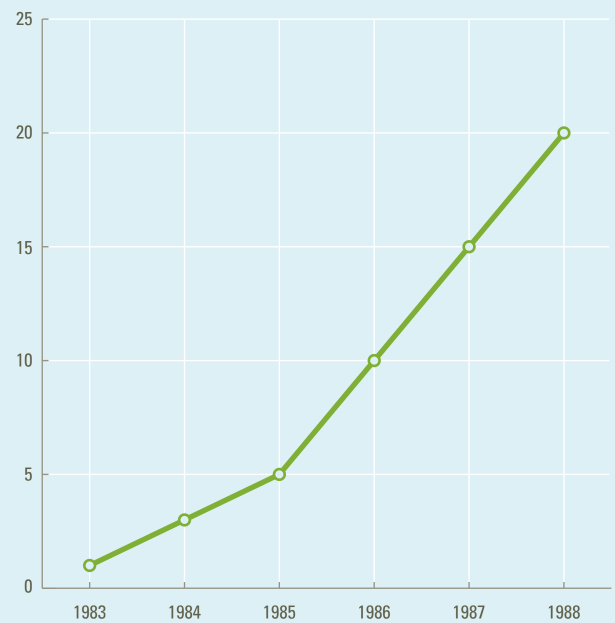
From 1976 to 1983, LBNL received $2 million ($5.5 million in current dollars) in funding from DOE "to support industry's low-e R&D efforts with thin film testing, field testing of low-E prototypes, annual energy simulations of low-e, and initial development of the WINDOW computer tool"[25] (discussed below). The lab awarded subcontracts to several private firms to develop prototype low-e coatings and thin film deposition processes. LBNL used its own staff and equipment for performance testing of low-e coatings and window prototypes.[26]

Around this time, a group of graduate students at the Massachusetts Institute of Technology were seeking a research project and decided to pursue the development of low-emissivity glass technologies.[27] The students formed the company Suntek Research Associates (later renamed Southwall Technologies), but they were unable to obtain private-sector investment because of the company's small size and the perception that low-e technology was unproven and risky.[28] They approached DOE and were granted $700,000 ($1.95 million in current dollars) in initial R&D funding[29] on the condition that they work with a national lab. The company chose to partner with LBNL and relocated from Massachusetts to California.[30] With the lab's help, Southwall developed Heat Mirror transparent film, the first low-e window technology to become a commercial product.[31] Released in 1981, the film was designed to be placed within the cavity of a multipane window.[32] (At that time, technology to deposit a low-e coating directly onto glass had not been fully developed.) That year, the first major project using Southwall's Heat Mirror technology, the City Hall for Spokane, Washington, demonstrated the feasibility and potential of low-e window technology.[33] This helped the company raise more than $10 million ($23.8 million in current dollars) in venture capital,[34] buy machinery, and begin manufacturing on a larger scale.[35]

Driven in part by the success of this startup, major window and glass manufacturers became more interested in low-e technology and accelerated their investment in low-e research, coating manufacturing, and window products.[36] The first two such companies, Andersen Windows and Cardinal Glass, stated that "DOE-funded efforts in the late 1970s and early 1980s were important factors in the critical decisions that led them to make [the] major capital investments" necessary to begin producing low-e glass and windows.[37] By the mid-1980s, industry investment in low-e manufacturing facilities had grown to $150 million ($320 million in current dollars), and "virtually every major window and glass company offered a low-e product."[38] Low-e windows rapidly increased in popularity, accounting for 20% of residential window sales by 1988.

Figure 2: **Residential Market Penetration of Low-E Windows, 1983–1988**[39]

(Percent of Sales)



Lawrence Berkeley National Lab developed freely available computer simulation tools that enabled the private sector to efficiently optimize designs and develop new low-e windows, lowering barriers to development and speeding diffusion of knowledge.

In addition to direct research support and physical prototype testing, Lawrence Berkeley National Lab created WINDOW, a computer model for simulating window performance. WINDOW was made freely available to the public to enable companies to test designs more quickly and inexpensively. Since there are many parameters to account for when low-e coatings are added to a window design, the ability to rapidly predict the performance of each variant is an important enabler of innovation. Stephen Selkowitz, leader of the Windows and Envelope Materials Group at LBNL, pointed out that this can be a very efficient use of government funds: "If you give a million dollar contract to one company, they might develop one product. If you put a million dollars toward these tools, and you distribute the tools widely, you might get 50 or 100 new products."[40]

Labeling and certification ensured product quality, allowing consumers to trust claims of window product performance prior to purchase.

The National Fenestration Rating Council (NFRC), a non-profit group that assigns ratings to windows based on their technical performance characteristics, requires the use of simulation tools (predominantly LBNL's programs) in order for a window product to be certified and receive an NFRC rating.[41, 42] With continued support from DOE, the suite of simulation tools has been continuously upgraded by LBNL to meet the evolving needs of manufacturers, the NFRC, code officials, and architects. Today, over 80% of all residential windows are modeled using LBNL's simulation tools and certified with NFRC ratings.[43]

The federal government adopted performance ratings and testing procedures initially developed by industry, ensuring reliable consumer information on energy-efficient windows that drove market uptake.

Through most of the 1980s, there was no standardized system for evaluating and rating window energy performance. This presented difficulties for marketing low-e windows. Since a low-e coating is invisible, and there was no clear way to demonstrate performance or impact, many consumers remained skeptical of the products' benefits.[44] Additionally, some manufacturers "made outlandish claims about the performance of their products," leading to consumer complaints and a federal investigation.[45]

In an effort to overcome lack of reliable consumer information and forestall federal regulation, window and glass manufacturers formed the National Fenestration Rating Council (NFRC) in 1989.[46] The NFRC immediately began developing a uniform system for testing and rating windows, as well as a labeling convention to inform consumers of window product ratings. In the Energy Policy Act of 1992, Congress authorized the NFRC to develop a federal voluntary window rating program and testing procedures, subject to the approval of the Secretary of Energy.[47] DOE found the NFRC's system to be satisfactory and gave it the required approval.

Use of the NFRC rating system was and still is voluntary at the federal level. However, federal sanction of NFRC standards spurred the establishment of mandatory standards at the state level, and today most U.S. states require that window products be rated and labeled by the NFRC.[48] Labeling and certification ensured product quality, allowing consumers to trust claims of window product performance prior to purchase. These efforts formed a necessary precursor to standards in the late 1990s and 2000s that would drive adoption of low-e products.

The government educated manufacturers (through targeted outreach) and consumers (through the voluntary ENERGY STAR program) about the benefits of energy-efficient windows, accelerating low-e windows' adoption in the marketplace.

In the late 1970s and early 1980s, as the first low-e coatings were being developed, homebuilders and window manufacturers lacked confidence in low-e window technology. They worried about the products' higher upfront cost slowing adoption, as well as the coatings' long-term reliability.[49] In response, the government worked to address both supply-side and demand-side information barriers.

On the supply side, LBNL undertook efforts to educate industry professionals and address their concerns about the new technology. LBNL staff attempted to influence key decision-makers by presenting their research results at industry trade shows and in private meetings with code officials, utilities, and research and marketing staffs from a number of major window manufacturers.[50, 51] These outreach efforts, as well as the use of low-e glass in a small demonstration building, helped convince the first two major window and glass makers — Andersen Windows and Cardinal Glass — to begin producing low-e windows at a large scale.[52] Additionally, starting in the 1990s, LBNL worked with the Alliance to Save Energy and the University of Minnesota to develop a set of online educational and training materials to inform the building industry about low-e window technologies and products.[53]

On the demand side, the federal government used a labeling program to incentivize low-e window usage. In 1992, the federal government established the ENERGY STAR program, which allows products that meet specified energy efficiency guidelines to be labeled and marketed with the ENERGY STAR logo and name.[54] The program initially certified just computers and monitors, but more product categories were soon added. Driven in part by the DOE Building Technologies Program,[55] ENERGY STAR standards for windows were added to the program in March 1998.[56] ENERGY STAR standards for windows were later integrated into other building codes and voluntary programs, such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) standards.[57] Additionally, ENERGY STAR certification formed the basis for tax credits established in the Energy Policy Act of 2005 to incentivize the purchase of energy-efficient windows.[58] Figure 3 shows the current ENERGY STAR window standards, which vary with geographic region in the U.S.

By rating products on a comparative basis, the ENERGY STAR program went beyond the NFRC ratings to emphasize to consumers the enhanced performance of low-e windows. ENERGY STAR was tremendously successful at driving adoption of energy-efficient windows, over 98% of which utilize low-e coatings.[60] Market share data began to be collected in 2001. From 2001 to 2010, market share of ENERGY STAR windows climbed from 35% to 81% of window sales—even as the requirements that windows must meet for ENERGY STAR eligibility were tightened on three separate occasions.

Figure 4: Market Share of ENERGY STAR Windows[61, 62]

(Percent of Sales)

Year in Which Specification Changed

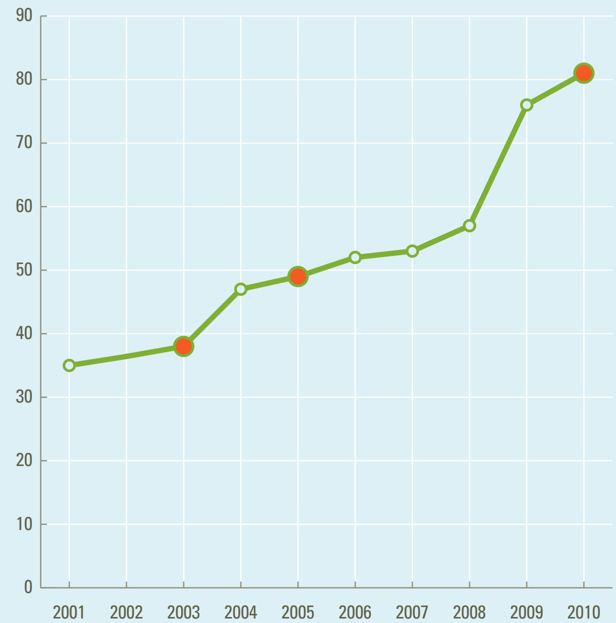


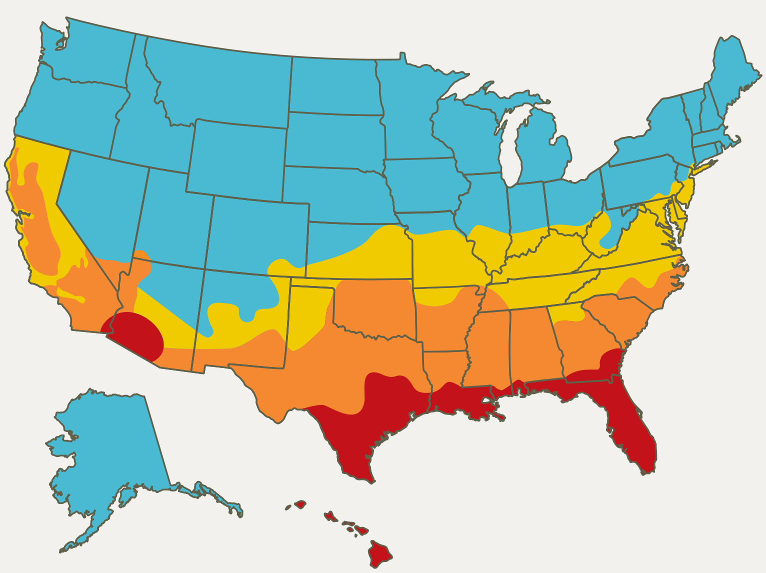
Figure 3: ENERGY STAR standards for windows.[59]

U-factor is a measure of how much heat a window allows to pass; a traditional, single-pane window has a U-factor of about 1.0. Solar Heat Gain Coefficient (SHGC) is a measure of how much heat from the sun penetrates the window.

	Windows		
Climate Zone	U-Factor*	SHGC**	
Northern	≤0.30	Any	Prescriptive
	=0.31	≥0.35	Equivalent Energy Performance
	=0.32	≥0.40	
North-Central	≤0.32	≤0.40	
South-Central	≤0.35	≤0.30	
Southern	≤0.60	≤0.27	

*Btu/h·ft²·°F

**Fraction of incident solar radiation



The results of the ENERGY STAR program demonstrate the tradeoff between generating widespread adoption and developing even more energy-efficient windows. John Meade of Southwall Technologies has pointed out that the ENERGY STAR standards for windows have been relatively lax. On the upside, this has led to widespread proliferation of windows with low-e coatings, but it has a "chilling effect on continued innovation" because manufacturers need not develop new, higher-performance products in order to maintain the ENERGY STAR label.[63] The U.S. EPA has similarly observed that the "ever-increasing market share suggests that innovation and/or cost-effectiveness in the market place is outpacing the specification revision cycle," suggesting that high market penetration of ENERGY STAR windows is partly because standards do not rise fast enough.[64] As a result, the EPA is aiming to reduce ENERGY STAR windows' market share to 41% with its next specification revision.[65]

Today, low-e windows command a market share of 80% of residential windows[66] and over 50% of commercial windows in the United States.[67] DOE-sponsored research investments from 1976-1983 totaling just $2 million ($5.5 million in current dollars, about $0.7 million/year), along with annual investments of similar magnitude during the rest of the 1980s and 1990s, resulted in a net savings of more than $8 billion by 2000 ($10.7 billion in current dollars).[68] The average payback timeframe for low-e windows is currently 6–16 (depending on climate),[69] and they may allow for the use of smaller and less expensive heating and cooling systems in new construction and major renovation projects, potentially saving money from day one. Whereas 30 years ago they might have been a novelty, low-e windows are now an integral part of the U.S. building sector.

Lessons Learned

The history of low-e windows demonstrates the importance of the government playing an active role in developing new energy technologies. Sometimes, even after a potential technology (such as low-emissivity coatings) is understood from a scientific perspective, the private sector may consider investing in the R&D necessary to commercialize that technology to be too risky. This is not an oversight on the part of industry. Private firms are rightfully concerned about investing in new technologies that may not be able to be developed into commercially viable products. The government is in a unique position: it has the laboratories, staff, and financial resources to investigate many technologies simultaneously, and government can take a long-term view, making high-risk, high-reward bets that would not pay off in time to satisfy investors in private sector companies. Thus, strategically directed government support that leverages and catalyzes industry engagement can lead to transformational technologies that revolutionize entire industries and achieve massive benefits for society.

For consumer-facing energy efficiency technologies, the government's role in creating performance and/or certification standards is critical to ensure proper market functioning. Objective performance metrics (such as the NFRC rating system) must be established to give consumers the information they need to choose between products, as well as to enable states and localities to integrate the technology into their building codes. Government can also improve new technology adoption through voluntary standards and labeling programs, such as ENERGY STAR, that help consumers distinguish between more and less efficient products. Standards and voluntary labeling programs should be kept up-to-date, tightening as the technology develops, to incentivize continued innovation and provide useful information about which are the most efficient products on the market.

By taking an active role in energy efficiency R&D, from project inception all the way through ongoing standard-setting and labeling, the government can work together with the private sector to achieve economic benefits, further U.S. technological leadership, improve public health, and protect the environment.

Acknowledgements

The authors would like to thank the following interviewees for their contributions to this paper:

Stephen Selkowitz, Leader of the Windows and Envelope Materials Group, Building Technologies and Urban Systems, Lawrence Berkeley National Laboratory

Marc LaFrance, former Technology Development Manager, Building Technologies Program, DOE Office of Energy Efficiency and Renewable Energy

John Meade, former Sales Manager, Architectural Products, the Americas, Southwall Technologies

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