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21st Century Windows: Electrochromic Windows and Other Glazing Technologies

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One of our challenges for the 21st century will be to try to reduce adverse societal impacts on our planet. Buildings account for one of the nation's largest energy costs and are the biggest source of greenhouse gas emissions. Within the building sector, windows were historically viewed as one of the "weak links" in buildings. The early response to this perspective was legislation to restrict window usage. The big conceptual leap in the last 25 years has been the recognition that better window technology and better building design can not only reduce these negative impacts, but can convert them into tangible human and economic benefits. The window industry has risen to the challenge of producing the cost-effective products that help translate researchers' predictions into market reality. A look at trends in glazing and new findings from an electrochromic window study by the Lawrence Berkeley National Laboratory (LBNL) provides some additional clues on where fenestration technology will take us in the 21st Century.

Two notable achievements have marked progress for the window industry in the last 25 years: Low-E coatings and spectrally selective "cool" glazings.

Low-E Coatings

First introduced in the United States in the early 1980s to reduce winter heat loss, low-emissivity (low-E) coatings for glass and plastic have now captured over one-third of the window market. Significant advances in quality control, production speed, and reproducibility of thin film coatings have dropped the manufacturing cost of these sophisticated multi-layer coatings to under $5 per square meter, making them affordable as a mass market product.

Improvements continue, such as reducing color and haze, lowering emissivity, improving handling properties and durability, and developing temperable coatings. Two low-E coatings can be incorporated into a three-layer insulating glass unit with gas fills and low-conductance spacers to reduce the heat loss of the unit below .6W/sq.m-K or about one-fourth the loss of a conventional double glazed window. Working closely with several window manufacturers, LBNL-installed prototype superwindows in homes in Montana and demonstrated that these products could outperform insulating walls on any orientation in the midst of winter. The high insulating value coupled with the window's ability to transmit modest amounts of diffuse skylight make it an energy winner compared to the insulated wall that can only lose energy.

Spectrally Selective Cool Glazings

In much of the U.S. the primary energy and comfort concern for windows is to reduce solar heat gain and cooling loads. A number of U.S. manufacturers have replaced the initial, clear, high-transmittance, low-E coating with an altered "spectrally selective" version that reduces solar heat gain by 50-to-70 percent compared to the first generation low-E coatings. This glazing normally features a double silver layer that reflects much of the sun's energy in the near-infrared portion of the spectrum but transmits most of the daylight. While the ratio of daylight transmittance to solar heat gain typically ranges from .6 to 1.0 for conventional glazings, spectrally selective glazings have a ratio of 1.1 to 1.8, so these glazings can deliver daylight into a room with only one-third of the associated cooling load of conventional tinted glazing

While these spectrally selective coatings are well suited to maximize the daylight/cooling load ratio, they can not dynamically respond to changing sun and sky conditions, control glare under sunny conditions or respond to occupant preferences.

Smart Glazings

The next big advances in coated glazings will be "smart glazings" that respond dynamically to the changing needs of the building and its occupants. Laboratory research on such coatings began over 20 years ago, and window-size prototypes of these coated glazings are now being readied for use in buildings. Smart glazings can be divided into two major categories:

- passively activated—respond to environmental conditions, includes the heat-sensitive thermochromic or the light-sensitive photochromic
- actively controlled—includes electrochromic, which can be switched as needed either manually or automatically with a small applied voltage.

Of these, we believe the actively controllable electrochromic glazings hold the most promise, although unresolved technical and market issues remain.

Electrochromic coatings are typically based on a three-layer sandwich, which is itself sandwiched between two more outer transparent electrically conductive coatings. The glazing darkens when a small voltage is applied across the coating and becomes clear again when the voltage is reversed. The coatings must switch reliably for many thousands of cycles. Thus, the amount of light and solar heat that passes through the window can be controlled, presenting a major opportunity for energy savings by reducing cooling loads due to sunlight and reducing electric lighting needs. In addition, electrochromic windows can provide privacy, and improve comfort. This technology could reduce peak electric loads by 20-to-30 percent in some commercial buildings and provide added daylighting benefits as well as improve home comfort and enhance productivity in the workplace. Until recently these savings could only be estimated from computer simulations because large samples suitable for field testing were unavailable.

Switchable Glazing Study

After many years of small-scale laboratory testing, several manufacturers are now working to scale up promising prototypes with good performance properties. Integrating the coatings and wiring into a window system and linking these technologies to the building energy management system remains a challenge. An ongoing LBNL study provides monitored data on the first full-scale demonstration of large-area electrochromic windows in an office setting in the U.S. Results indicated that the electrochromic window system tested provided:

- excellent optical clarity
- no coating aberrations (holes, dark spots, etc.)
- uniform density of color across the entire surface during and after switching

- smooth gradual transitions when switched
- excellent synchronization or color matching among a group of windows during and after switching.

The windows had a very slight yellow tint when fully bleached and a deep Prussian blue when fully colored. When viewed from outside, the nonreflective, electrochromic windows looked exactly like conventional tinted windows except that the coloration could be changed. The absence of window shades gave them a high-tech, spare appearance.

The LBNL study was conducted in two identical side-by-side offices in the Federal Office Building in downtown Oakland, Calif. In each room, five lower electrochromic "view" windows (.6m x 1.7m) and five upper electrochromic "daylighting" windows (.6m x .4m) formed a large glass window wall. The southeast-facing electrochromic windows had an overall visible transmittance (Tv) range of almost 4 to 1 (11-to-38 percent). The glazing properties were controlled by sensors and integrated with a dimmable electric lighting system to provide constant illuminance appropriate to a work environment and to control direct sun intensity. Although the system has an automatic operating mode, provision is made for manual override. Daily lighting energy use from the automated electrochromic window system decreased by 6-to-24 percent when compared to the energy use of static, low-transmission (Tv =0.11), unshaded windows in overcast to clear sky winter conditions in Oakland.

Even on days when lighting energy savings were not obtainable, the visual environment produced by the electrochromic windows, indicated by well-controlled window and room luminance levels, was significantly improved for computer tasks throughout the day, compared to the visual environment that resulted from unshaded glazing with 38 percent transmittance. Cooling loads were not directly measured in this test, but previous testing and building energy simulations indicate that additional savings could be achieved, Electrochromics may require occasional use of interior or exterior shading treatments in the presence of intense direct sun to ensure visual and thermal comfort.

These results signal the beginning of a new development phase. Just as with the early introduction of low-E coatings, it will take time to build confidence in the technology, to solve the systems integration issues, and to improve manufacturability to reduce costs to end users. New research results will help electrochromic developers improve their coating designs and will address issues such as switching speed, coating color, brightness perception, and privacy -- all needed to help further understand the performance characteristics of this emerging technology. Glazing suppliers and window manufacturers will also have to forge new liaisons with both lighting systems and building control systems suppliers. Architects, engineers and specifiers will be faced with new design challenges, but even greater design opportunities. Although the financial investments initially will be high, the payoffs can be even higher with a building façade that provides architectural design freedom, minimizes cooling loads, maximizes daylighting energy benefits, controls glare and enhances thermal comfort.

Glazings as Energy Suppliers and Managers

Given the current advancement of fenestration technologies, greater emphasis is likely to be placed on using the building facade as a dynamic filter and a source of on-site heat, light, and electric power. An analysis of how energy flows interact with a building facade reveals there is adequate energy available at a building site to power most buildings. The architect and engineer will need more powerful tools to assess the dynamic performance of the new window technologies under a wide range of environmental and user conditions. At the same time, the decision makers will need reliable product data that accurately and fairly describes the properties of these new technologies. Manufacturers and organizations such as the National Fenestration Rating Council, which administers a voluntary, uniform rating and labeling system for the energy performance of windows, doors, and skylights, may well have an expanded role to play as the fenestration industry becomes cognizant of the need to provide customers with reliable performance information about window products as an integral part of the building system.

The window industry is well positioned to take advantage of the changing social, business, and technical environment. The industry has already reinvented itself once in the last 30 years to address the transition to high performance static windows. In the 21st Century, windows increasingly will be viewed as dynamic and intelligent elements that are part of integrated building systems rather than as static, stand-alone building components. And these new window systems will be better suited to meeting occupant needs, owner budgets and societal imperatives.

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