Electrochromic Smart Windows: Toward an Energy Efficient Architecture

The spring 2001 issue of *Interface* pointed at the imminent dangers to humankind associated with global climate changes, due to excessive use of fossil fuel, and argued strongly for the role of electrochemistry and photochemistry in benign technology devised to alleviate some of these dangers. The examples put forward in *Interface* included fuel cells, carbon dioxide sequestration, etc. This contribution emphasizes the possibilities of electrochromic smart windows for diminishing the need for electrically driven air conditioning and hence for energy efficiency, along with enhanced comfort, in buildings. The electrochromic smart window is capable of varying its transmittance upon charge insertion/extraction in electrochemically active materials—normally being thin film based on transition metal oxides.[1]

To set the scene, we note that heating, cooling, lighting, ventilation, and powering of buildings account for about half of the total energy consumption in the European Union and are hence responsible for more energy consumption than any other end-use sector such as transport or industrial production. Most of this energy is produced by fossil fuel; it leads to the emission of carbon dioxide and concomitant global heating.

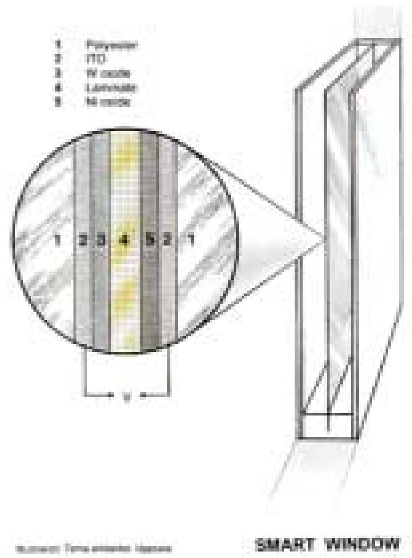

FIG 1. Conceptual smart window including laminated and coated plastic foil suspended between two glass panes. The window also includes a coating with low thermal emittance—prepared using known technology—whose role is to prevent the energy absorbed in the foil from being radiated into the room (not shown).

Buildings need windows to allow the occupants visual contact with their surroundings and to provide daylight but from an energy perspective, the windows are problematic, and they normally either let in too much energy, so that cooling is required to create a good indoor climate, or they let out too much energy so that heating is needed. In modern commercial buildings, the problem of excessive heating normally dominates in all parts of the world, and below we only consider cooled buildings.

There are numerous measures to avoid overheating by too much solar energy entering through windows, with blinds, awnings, and shutters having been used for long times. Multiple glazing diminishes heat transfer across the window aperture. Also the glass itself can be modified, normally by a "solar control" coating based on silver which reflects part of the infrared solar radiation. Nevertheless, cooling remains a huge problem—and it is aggravated by the increased use of personal computers and other office machines—so that power consumed in cooling equipment now dominates the utilities' peak loads in parts of the world. It should also be emphasized that efficient solar control by today's technology tends to lower the visual transparency, thus compromising the windows' primary function: that of providing unmitigated visual contact with the ambience. Electrochromic smart windows are able to lessen the need for air conditioning. The first commercial product was introduced in the fall of 1998 and is now being installed in some prestige buildings.[2]

Figure 1 illustrates a prototype design of an electrochromic smart window. The central part is a transparent ion conducting polymer laminate. It allows the shuttling of ions between electrochromic films of tungsten oxide and nickel oxide. This three-layer stack is interposed between polyester sheets (or glass panes) with transparent electrically conducting layers of indium tin oxide (ITO). When a DC voltage of 1 to 2 V is applied between these ITO electrodes, charge is moved from the nickel oxide to the tungsten oxide with the effect that both of these films darken gradually. When charge is moved in the opposite direction, both films are able to retain their transparent state. A voltage needs to be applied only when the optical properties are being altered, *i.e.*, the device exhibits open circuit memory. The visible transmittance hence can be modulated between widely separated extrema such as 7 and 75%. Figure 2 illustrates typical data for a research-type polyester-foil-based device.

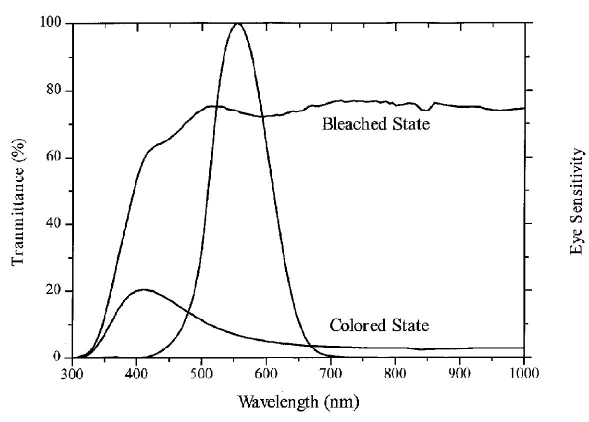

FIG 2. Spectral transmittance of an electrochromic foil in fully darkened and bleached states. Also shown is the sensitivity of the human eye. The visible transmittance is 73.5/7.1% in the bleached/colored state.

Smart windows are able to provide comfort for the users of the building as well as energy efficiency. The comfort issue is obvious since glare and thermal loads can be lessened at will. The energy efficiency has been harder to come to grips with but recent work[3] has specifically focused on a new overriding control strategy: to have the windows in a room in their dark state when no one is present and to have them transparent—according to individual choice—when the room is in use. Quantitative energy savings can be estimated for this control strategy from a simple back-of-an-envelope calculation. For simplicity we take the solar energy density falling onto a window to be 1000 kWh/m^2 yr. This is regarded as a typical number for a south-facing window, and more correct values for south-facing/north-facing/horizontal surfaces would be 850/350/920, 1400/450/1700, and 1100/560/1800 kWh/m^2 yr for Stockholm, Sweden, Denver, USA, and Miami, USA. Half of this energy, 500 kWh m^2 yr, is visible light; we only include this latter value for the smart windows, because the infrared radiation in principle can be intercepted by known, static technology. With the window varying the transmittance between 7 and 75%, the energy savings inherent in the controllability is 340 kWh/m^2 yr, *i.e.*, this is the difference between having the window in its darkest state and in its fully bleached state. But when should it be dark, and when should it be transparent? With physical presence as the overriding control strategy, we then need to contemplate when a typical room in a cooled (commercial) building is used – or rather the fraction of the solar energy which enters when someone is present in the room. Considering that the room is expected to be empty during holidays, weekends, early mornings and late afternoons (when the sun is standing low), we believe that 50% represents a conservative estimate of the relative solar energy that enters the room when it is unoccupied. A minimum value for the energy savings then is 170 kWh/m^2 yr. In a real case, the smart window would not be fully transparent during at least some of the time it is used, so that the energy savings would in fact be larger.

The energy savings may be appreciated by a simple analogy: Replacing the window aperture with a solar cell module—assuming today's best thin film solar cells with about 17 % efficiency—will generate 170 kWh/m^2 yr under the given conditions. The energy savings implied in smart windows is then the same as the electrical energy generated by the solar cell module in the same position. The analogy presumes air conditioning powered by electricity generated with a coefficient of performance (COP factor) equal to one, as is commonly done in national scenarios for electricity generation.

The emerging picture of workplaces in commercial buildings is then one with desks placed at the smart window, powered by solar cells so that external wiring is not required. Sensors measure lighting levels on the work surface and globally in the room; other sensors register temperatures and physical presence. The light sources include power regulation. Wireless communication takes place among the various components, in line with the concept of an "intelligent building." The interior climate is set via a remote control and communication unit capable of operation in several modes: 1. Manual setting of lighting and temperature according to individual choice; 2. Setting according to a preprogrammed "comfort profile" for the person occupying the room; and 3. Setting minimizing the energy use in the building.

The smart windows technology may be cheap, provided that the production is carried out effectively. If continuous roll coating and lamination are used, the manufacturing cost of the foil—including materials, equipment, and personnel—is estimated to be of the order of 10 US$/$m^2$. Sensors, power supply, and wireless communication systems must be added to the system cost for accomplishing high comfort and energy efficiency. ■

References

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3. C. G. Granqvist, *Int. Glass Rev. (2)*, **67,** (2001).

About the Author

Claes G. Granqvist *is a Professor of Solid-State Physics at the Ångström Laboratory, Uppsala University, Sweden. He may be contacted at Claes-Goren.Granqvist@angstrom.uu.se.*