ELECTRONICALLY TINTABLE GLASS: THE FUTURE OF HIGH PERFORMANCE FACADES IS HERE

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ABSTRACT

We live in a dynamic environment, but until now our building envelopes have been static in nature – unable to effectively control the flow of the sun's light and heat into buildings from hour to hour and from season to season. Electronically tintable glass provides the means to develop a dynamic façade with variable visible light transmission and solar heat gain coefficient, which saves cooling and lighting energy, and solves problems of excessive solar heat gain, glare, fading and the need for unsightly blinds. In fact, the U.S. Department of Energy (DOE) states that their goal of a zero energy building in 2030 cannot be achieved without the use of dynamic glazing. Electronically tintable glass is now commercially available and is being actively specified and installed in building envelopes.

This paper will briefly review dynamic electrochromic glass performance characteristics, and will then focus on a number of diverse case studies to demonstrate the application of electrochromic glass in different building types and glazing applications to achieve different objectives such as glare control, heat control and occupant comfort. Integration and automation of control will also be discussed.

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INTRODUCTION

The environment changes season-by-season, day-by-day, and hour-by-hour, yet the traditional building envelope cannot respond to these ever-changing conditions. The static nature of glass leads to significant problems related to heat and light control, occupant comfort and productivity, and energy consumption.

While a full range of glazing products has been developed—from highly reflective to spectrally selective low-emissivity glass—these are still static in nature and cannot actively respond to varying exterior sunlight and heat conditions. Consequently, an architect must make compromises in addressing a building’s combined need to manage solar energy, daylight and glare, while maintaining the window’s intended use—that of a view outside. Building occupants typically resort to using shades or blinds to control glare, which negates the purpose of the window and still does not solve the problem of heat gain since solar energy still enters the building and must be thermalized.

Certain dynamic glass technologies can help building owners, designers, contractors and occupants avoid such compromises and challenges. Products with these technologies are now being incorporated into building designs. It is therefore important for designers to understand dynamic glass systems in order to specify the optimum solution for their projects. This paper discusses the use of dynamic electrochromic glass technology in building envelope applications. It focuses on the performance characteristics of electrochromic glass, and then looks at case studies that show the application of dynamic glass in different building types and glazing applications to achieve different objectives such as glare control, heat control and occupant comfort (Figures 1 and 2).

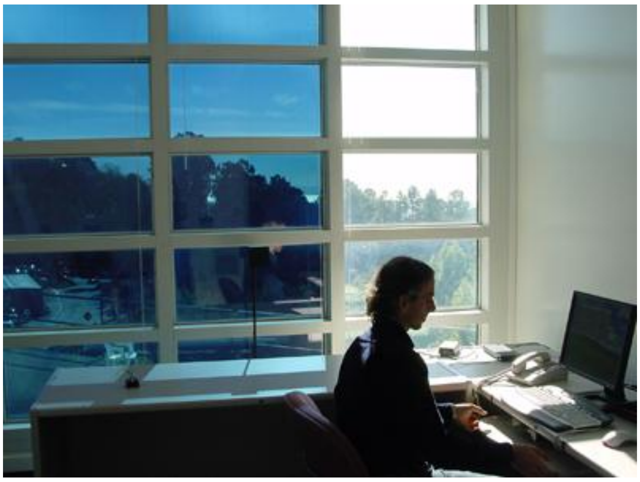

FIGURE 1: Electrochromic glass installed in a curtainwall at the United States’ Lawrence Berkeley National Laboratory showing the electrochromic glass in both highly transmitting and tinted states. Note the glare falling across the keyboard on the desk.

FIGURE 2: The same installation, with a different set of panes in the tinted state. Note the reduction of glare, preservation of view, and daylighting flexibility from zone control.

CURRENT DESIGN ISSUES AND BENEFITS OF DYNAMIC GLASS

Glass is ubiquitous in buildings because of the positive impact that natural daylight and the connection with the outdoors have on people's health and well-being. Despite these desirable benefits, windows are also the greatest cause of thermal and visual discomfort in buildings. According to the U.S. Environmental Protection Agency (EPA), they are the largest source of unwanted heat loss and heat gain, and must be managed by the heating, ventilation and air conditioning system (HVAC).

Electrochromic glass products switch electronically between a highly transparent state and a darkly tinted (low heat gain) state, so are able to match varying solar conditions. In this manner, electrochromic products offer increased thermal and visual comfort, daylight control and energy savings without loss of view. With electrochromic glazings, architects can for the first time design larger areas of glass into the building envelope to capitalize on the beneficial aspects of the sun while at the same time minimizing its negative effects. For these (and other) reasons, electrochromic glass is a potential point-earner in the U.S. Green Building Council's Leadership in Energy and Environmental Design® (LEED) Rating System [1]. In addition, electrochromic insulating glass units (IGUs) are easily integrated into typical framing systems because they are nearly identical to traditional IGUs, the only difference being (from a fabrication standpoint) that they have a wire extending from one edge.

The EPA estimates that up to 30% of commercial buildings' energy is used for lighting and as much as 80% of this lighting energy results in heat, which must be removed by air conditioning. Additionally, HVAC systems account for more than 35% of energy use in commercial buildings. In an assessment conducted by Lawrence Berkeley National Laboratory (LBNL), electrochromic windows were shown to save up to 60% of daily lighting energy [2].

The U.S. Department of Energy (DOE) predicts that commercial buildings relying on electrochromic window systems could save up to 28% in energy costs when compared to buildings with static, spectrally selective, low-e windows. The DOE also reports [3] that electrochromic glass products can help achieve:

- 10-20% operating cost savings;

- 15-24% peak demand reduction;
- Up to 25% decrease in HVAC system size.

Also, the DOE has a goal of attaining "Zero Energy Buildings" in commercial structures by 2030. The DOE has stated that this goal can be achieved only with use of dynamic glass.

Other benefits of dynamic electrochromic glass include:

- Fading protection (see Reference Table 1, below);
- Low maintenance (unlike blinds, electrochromic technology has no moving parts);
- Unhindered window views;
- Reduced eyestrain due to reduced glare on computer screens and televisions (see Figures 1 and 2, above).

CURRENT ELECTROCHROMIC PERFORMANCE CHARACTERISTICS

Electrochromic glass products change from a highly light-transmitting state (60-70% T) to a highly tinted state (3-4% T). This range is critical to effectively reducing glare and its associated thermal energy, yet still providing the desired level of natural light. The electrochromic glazing's ability to dynamically block both visible and infrared solar radiation provides for a unique modulation in solar heat gain coefficient (SHGC) from 0.48 (clear) to 0.09 (tinted) **(Figures 3 and 4)**. Such systems are low power, requiring 2.8 W/m^2 (0.28 W/ft^2) on average over five to ten minutes to switch, and 1.0 W/m^2 (0.1 W/ft^2) to hold the tinted state.

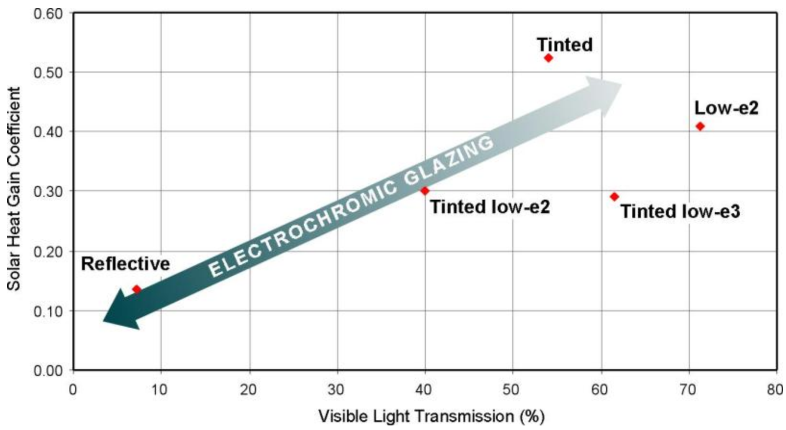

FIGURE 3: Illustrates the dynamic range of an electrochromic glazing in both visible light transmission (T_{vis}) and solar heat gain coefficient compared to some examples of generic static glass options available on the market today. With dynamic glass, designers do not have to make a compromise between SHGC and T_{vis}. With static glass, designers must pick one set of SHGC and T_{vis} properties and then live with it for the life of the building.

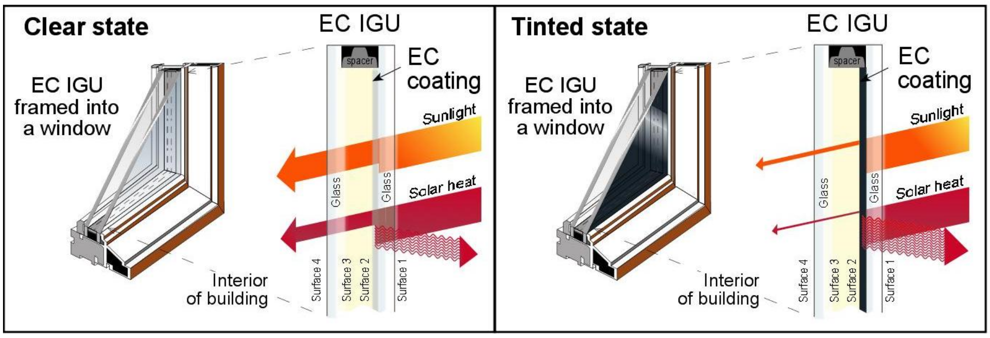

FIGURE 4: Illustration of the unique heat and light modulation capabilities of electrochromic glass.

HOW ELECTROCHROMIC TECHNOLOGY WORKS

An electrochromic material is one that can change its light and heat absorption reversibly with the application of a voltage. Electrochromic coatings consist of five layers (Figure 5): Layers 1 and 5 are transparent conducting (TC) oxides, which provide for uniform electrical distribution. Layers 2 and 4 are the electrochromic (EC) and charge storage (CS) materials respectively, and layer 3 is an ion conductor (IC), which allows conduction of ions, but not electrons. When a low voltage direct current (<5 V) is applied across layers 1 and 5, positively charged ions (lithium ions, Li+), which are deposited into the charge storage layer during manufacture, move across the ion conductor into the electrochromic material at the same time that an electron (e-) is also inserted into the electrochromic layer. This causes the electrochromic layer to absorb light and appear tinted. When the voltage is reversed, the process is reversed and the product reverts to its clear or “off” state.

Monolithic solid state electrochromic devices consist of a stack of five ceramic metal oxide coatings on a single piece of glass. The advantages of this configuration are that it’s durable—since it is an all-ceramic, inorganic system—and it can easily be integrated into industry standard insulating glass units (IGUs).

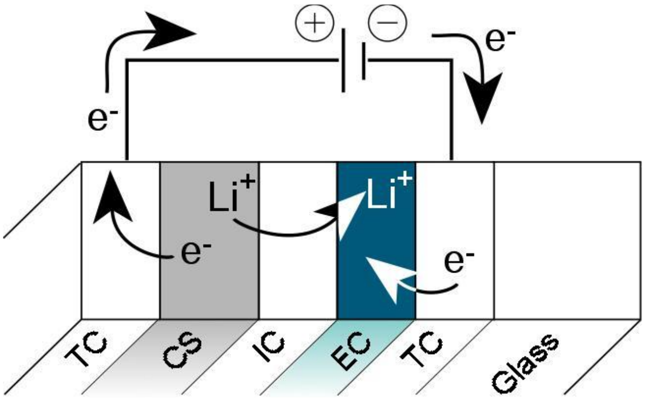

FIGURE 5: How an electrochromic device is constructed and works. Key: TC = transparent conductor, EC = electrochromic layer, IC = Ion Conductor, CS = charge storage layer, Li+ = lithium ions, e- = electrons. Insertion of lithium ions and electrons into the EC material causes it to absorb light (tint).

TABLE 1: The performance parameters of electrochromic (EC) glass in both the clear and tinted states as compared to clear low-e glass.

	Visible Light Transmission (Tvis)	Solar Heat Gain Coefficient (SHGC)	U-Value BTU/ft^2 °F U-Value	UV Transmission	Fading Protection^
EC Clear	62%	0.48	0.28	6%	82%
EC Tinted	3.5%	0.09	0.28	0.8%	98%
Clear Low-E2 *	68-72%	0.35-0.42	0.25	10-15%	65-71%

*Low-E2 data represents a range of products available, which trade off Tvis for lower SHGC.

^KDF measures the amount of the sun's radiation that causes fading, which is transmitted through the glass. Fading protection is 1-KDF.

Data based on one-inch, argon-filled IGU, calculated using WINDOW 5.2.

CASE STUDIES

Here we will highlight case studies that illustrate the range of building types and applications in which dynamic glass can be used to provide light and heat control without loss of view to the outside.

Office Space

The two major complaints in office buildings are that it is too hot or too cold [4] and this discomfort can be attributed in part to the energy inefficiency of the building envelope and the inability of HVAC systems to deal with excessive heat load on the building's perimeter zones versus its interior zones. Offices on the perimeter have a tendency to overheat in the summer and are too cold in the winter, plus occupants are affected by glare on their computer screens. Given that the largest expense in an office building is salaries (by a factor of more than 10 over utilities and rent), it makes sense that office environments should be designed to promote productivity.

Case Study 1. Our first case study involves a large skylight (2500 ft^2 [230 M^2] of glass) over an office space in Greenwich, Conn. The original method for controlling heat gain and glare from the skylight was to pull a tarpaulin over the entire skylight in the spring and remove it in the autumn! Although the tarpaulin blocked the heat and glare, it also closed in the space, eliminated the natural daylighting and removed the connection to the outside. During a renovation late in 2008 the owner re-glazed the skylight with electrochromic glass.

The electrochromic control system takes power from building integrated photovoltaic panels installed at the bottom of each skylight ridge and provides automatic intermediate state control based on a user-defined light level in the occupied space. The result is a comfortable work space that provides natural light, heat and glare control for the occupants (**Figures 6-8**).

FIGURE 6: The exterior view of the electrochromic skylight installation in Connecticut. The photovoltaic panels that power the skylight system runs along the bottom of the skylights.

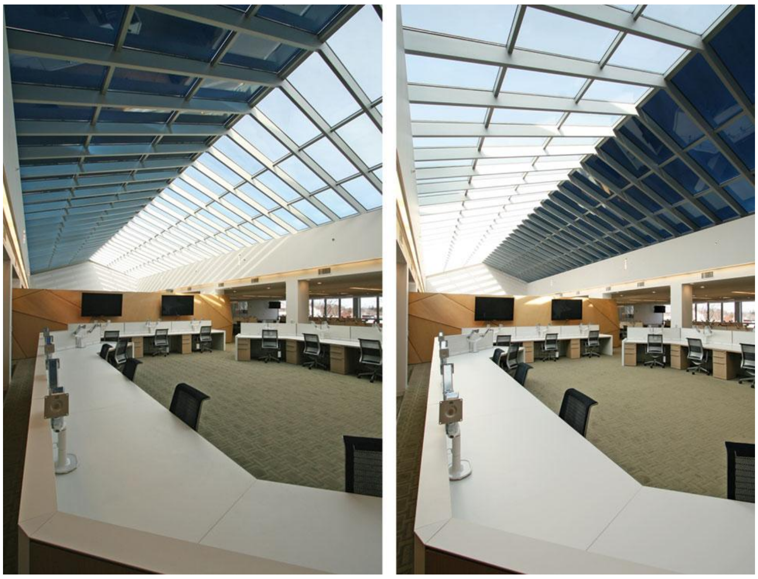

FIGURE 7: East- and west-facing banks of the ridge skylight are programmed to change according to the location of the sun. The roof can also be completely tinted or completely cleared, or switched in any combination of its eight zones.

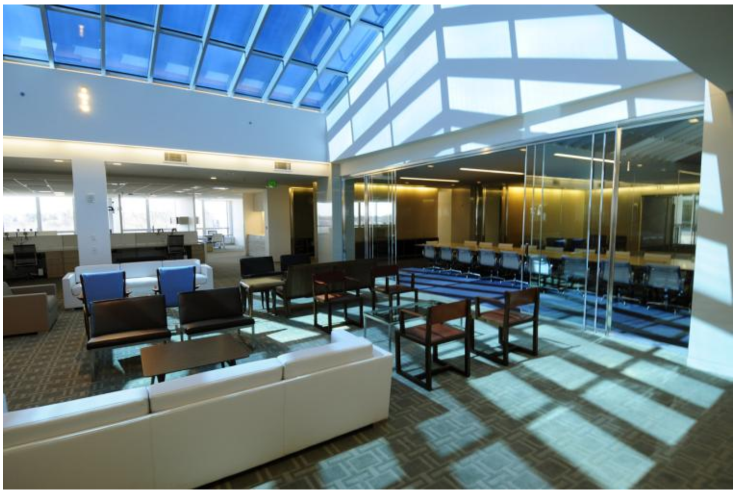

FIGURE 8: When in an intermediate state, the skylight blocks the heat while allowing the room to maintain a bright, pleasant ambience.

Case Study 2. The Windows and Daylighting group at LBNL has completed a study to evaluate the energy savings that can be derived from the use of electronically tintable glass integrated into building lighting systems (test site shown in **Figure 1**). In this second case study, we look at a side-by-side comparison of rooms with dynamic electrochromic glass and static glass. In this comparison, LBNL found that electrochromic glass provided a reduction in energy usage of 5-20% for cooling on sunny days compared to low-e with or without venetian blinds [2], 44-59% [6] lighting energy savings over 15% visible light transmitting glass, as well as a 19-26% [5] savings in peak demand versus high performance spectrally selective low-e glass (T_{vis} = 42%, SHGC = 0.22). In addition, researchers evaluated the human factors impact and found that their test subjects preferred to work in the rooms equipped with electrochromic glass more than the room with static glass and the interior shading system.

Case Study 3. Another application for electronically tintable glass is in conference rooms where light control is essential for audio-visual presentations and where the ability to bring a maximum amount of natural daylight in and maintain a view and connection with the outside promotes a productive environment in the room. In this third case study (**Figure 9**) we show the use of electrochromic glazing in a conference room where it is integrated into a lighting control system and provides integrated, automated control of light level as well as manual override when the room needs to be darkened for audio-visual presentations.

FIGURE 9: A conference room where audio-visual presentations are often given is an application well-suited for electrochromic windows.

Restaurants

Case Study 4. Late afternoon and early evening are key business times for restaurants, and those that have a view to the ocean or lakes, for example, can command premiums on pricing. Unfortunately, if the view is west facing, the glare during dinner service can be so uncomfortable that blinds have to be pulled and the view that the customer was expecting, and for which they are probably paying a premium, is lost. In this fourth case study, electrochromic glass is installed in wood windows in an Italian style restaurant overlooking a lake in Wisconsin, U.S., to reduce glare throughout the year, including in winter when ice and snow exacerbates the problem. As can be seen, no shading systems are required and the view is preserved. See **Figure 10**.

FIGURE 10: Electrochromic windows find application in restaurants where the view is particularly important, as it is in this establishment situated on the edge of a lake in Wisconsin, U.S.

Educational facilities

Case Study 5. A number of studies have shown that access to natural daylight in educational facilities promotes learning [7], and indeed, an uncomfortable learning environment that is too hot or too cold or with glare can also impair concentration and productive learning. In this fifth case study (**Figure 11**) electrochromic glass has been integrated into a curtainwall in a library at a tertiary education college (Century College) in Minnesota, U.S. to provide heat and glare control. In this application the dynamic glass is installed into the bottom and the top three rows of the curtainwall, and static, high-performance, tinted low-e glass is installed in the center rows. This installation clearly shows the contrast between electrochromic and static glass, and illustrates the compromise that designers have to make when using static glass for heat and light control.

FIGURE 11: Electrochromic glass in a library in a tertiary education college in Minnesota, U.S. The top three and bottom rows are electrochromic glass; the middle rows are static, tinted, low-e glass.

Case Study 6. The room-darkening capabilities of electrochromic glass are beneficial in classrooms such as the one shown in our sixth case study (**Figure 12**) where electrochromic glass has been installed in a science laboratory in an elementary school in Elk River, Minnesota.

FIGURE 12: An elementary school in Minnesota, U.S. has electrochromic glass in its science classroom.

Religious facilities

Case Study 7. These buildings are becoming more multi-use, and in particular are using more audio-visual presentations. Such structures are also designed with many windows to bring in daylight and connect with the world outside. This therefore creates challenges for light and heat control through the changing seasons and through the day. In the seventh case study, we look at electrochromic glass that has been installed in a chapel by the Diocese of Colorado, U.S. (**Figure 13**). The control system for the glass is integrated into a thermostat to control switching based on the temperature of the room. Previously this chapel could not be used because it was always too hot and furnishings and artwork were damaged by exposure to the sun. Now the chapel is in regular use and the space is comfortable for the occupants.

FIGURE 13: Because of the heat gain in the chapel at the Diocese of Colorado, the room was unusable until electrochromic glass was installed.

Medical facilities

Case Study 8. It has been found that access to natural daylight speeds healing [8]. In medical facilities, however, cleanliness is essential and, conventionally, shades and blinds are added to any windows to control light because of the glare and heat issues described above. However, shades and blinds harbor dirt, dust and bacteria and therefore can cause problems in these locations. Hospital rooms are therefore key applications for electronically tintable glass. In addition, cleanliness requirements are particularly acute in operating rooms and therefore generally preclude the use of windows in these areas. In this eighth case study, we show the use of electronically tintable glass in a state-of-the-art operating room for cardiac surgery (Palm Desert Regional Medical Center, California, U.S.). Reduction in light levels is provided during procedures and video conferencing, while allowing natural daylight during set-up and take-down (**Figure 14**).

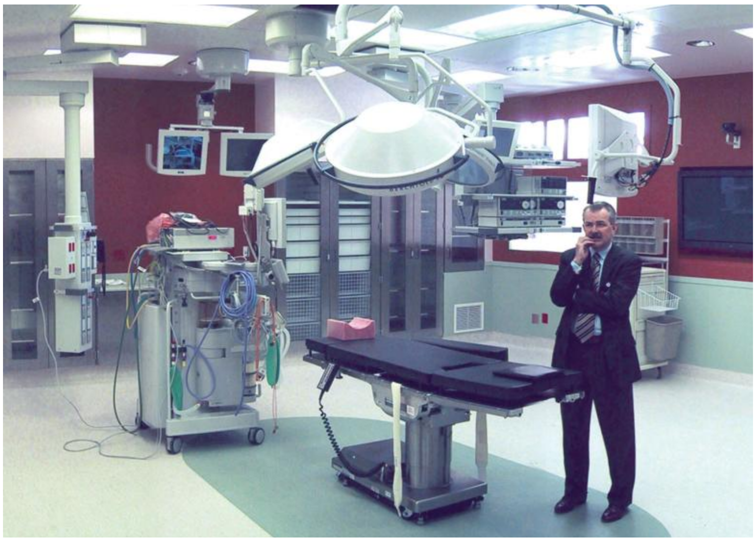

FIGURE 14: Historically, operating rooms (ORs) have not been able to have windows because of the necessity of shades and blinds, which are dust and bacteria collectors. Electrochromic glass allows windows into ORs because shades and blinds are no longer necessary for solar control.

As clearly illustrated in these case studies, electrochromic glazing can provide significant benefits in many building types and applications for a variety of purposes, as promised by many earlier studies. The light and heat control that electrochromic glass offers will also undoubtedly find application in many other applications—wherever dynamic heat and light control are needed.

COST

Electrochromic glazings can be comparable to (and in some cases lower than) today's static glass solutions. Even with high-performance static low-e, additional methods of solar control (exterior sunshades, interior shading systems, larger HVAC capacity) are frequently required to complete the static glass solution. When adding up these initial costs (in addition to the higher ongoing energy expenses), the similarity in costs becomes apparent (**Figure 15)**. With the static glass system, the building owner also has the potential reduction in productivity due to comfort issues, which, as discussed above, is a great deal more costly than other operating expenses. Worst of all is the loss of the primary reason we put windows in a building in the first place – to see out.

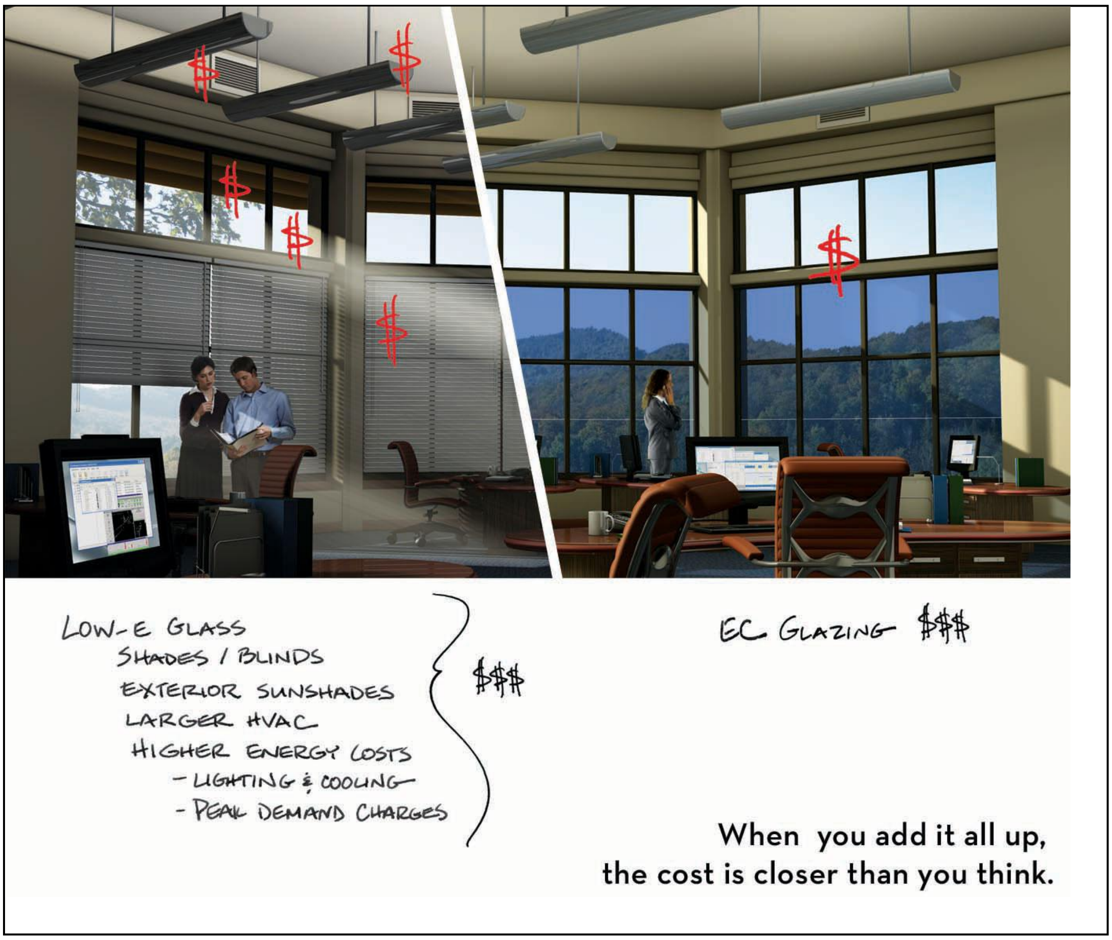

FIGURE 15: A comparison of electrochromic glazing (on the right) with low-e glass and its accompanying solar-control add-ons, which are necessary to make the space functional.

CONCLUSION

Electronically tintable glass is the future of the building envelope. It allows people to dynamically control the heat and light flow into a building depending on the needs of the occupant and the changing outside environment. Control systems can be fully automated, manually controlled or hybridized, and they can be integrated into other building systems, such as lighting or AC, to provide optimized control and energy efficiency. The case studies discussed here clearly demonstrate in real applications the significant benefits for heat and light control, energy savings, occupant comfort and view preservation that can be provided by the use of electronically tintable glass.

ACKNOWLEDGEMENTS

We would like to thank the entire team at SAGE Electrochromics for their work in realizing these case studies.

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