Electronically Tintable Glass as an Architectural Enabler

Helen Sanders, PhD[1] and Louis Podbelski, AIA, CSI[2]
SAGE Electrochromics, Inc.

ABSTRACT

With ever more stringent energy codes and the march towards zero energy buildings, architectural design freedom using glass over large glazed areas may become more constrained as windows are increasingly viewed as the weak energy link in the building envelope.

However, electronically tintable glass, also known as electrochromic (EC) glass, allows the building façade to become dynamic, changing the transmission of the sun's heat and light in response to the exterior environment and the needs of the building's occupants. By modulating the visible light transmission and solar heat gain coefficient across a wide range, EC glass provides both energy savings and enhanced thermal and visual comfort to the building occupants without obstruction of the view.

The availability of such a product technology provides architects with a tool that can expand design possibilities and enable the creation of exceptionally energy efficient and comfortable day lit spaces that would otherwise not be possible. This paper describes a number of case studies which illustrate the use of EC glass as an architectural enabler. In one project the designer was able to implement a ductless, naturally ventilating, heating and cooling system in a two story south- and west-facing atrium in California that would not have been possible without the use of dynamic glass. In another case study, EC glass is used in skylights to provide natural daylight throughout the building and sufficient solar control to allow for a space with no air-conditioning.

INTRODUCTION

Will ever more stringent energy codes mean that highly glazed buildings are a thing of the past? Will architectural design freedom using glass be constrained as we move towards zero net energy buildings? These are questions being asked more often now as windows are increasingly viewed as the weak energy link in the building envelope [Wilson 2010, Shuttleworth 2008]. Glass is an important tool for daylighting and having the right amount of glass in the right place on the façade can offset electric lighting usage significantly if used in conjunction with dimmable lighting controls. However, with insulating values lower than walls, and at times the cause of unwanted solar heat gain, there is an upper limit in glass area beyond which the additional HVAC loads due to heat gains and losses begin to outweigh the electrical lighting savings, even with an optimum daylighting design. In an environment of ever-increasing building energy performance goals, constraining the amount of glass area in buildings is being widely debated. Indeed, in both Europe and North America we are seeing an increasing trend to reduce window to wall ratio in new building energy codes and standards through either increasing stringency for insulation

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[1] Vice President, Technical Business Development, SAGE Electrochromics, Inc., Faribault, MN, USA.
[2] Vice President, Architectural Solutions, SAGE Electrochromics, Inc., Faribault, MN, USA.

values and whole building energy efficiency targets [The Building Regulations, Part L, 2010] or through additional specific window area limits [IECC 2012].

However, glass is also a key architectural design tool and is ubiquitous in buildings today because of the design flexibility it provides and the positive impact that natural daylight and the connection with the outdoors have on people's health and well-being. Constraining the amount of glass that can be used certainly puts limitations on an architect's design freedom. However, it is also true that too much glass or glass in the wrong location on the building can cause uncomfortable glare and heat for the occupants, as well as a large air conditioning load. Moreover, because we live in a dynamic environment which changes season-by-season, day-by-day, and hour-by-hour, a traditional "static" building envelope cannot respond effectively to these ever-changing conditions, even if glass is strategically placed around the façade and overhangs employed. Indeed, a static envelope is increasingly becoming a constraint when balancing architectural design with occupant comfort and the rising demands of energy efficiency.

Figure 1: Graph of visible light transmission (T_{vis}) versus solar heat gain coefficient (SHGC): This chart shows the heat gain and light transmission range of a high performance EC product compared with some examples of standard static glass.

The US Department of energy has identified three key façade elements required in order to achieve net zero energy commercial buildings [Arasteh et. al., 2006]: Low U-factor fenestration (reduce conductive losses), dynamic solar control (admit or block solar heat gain and light as needed) and integrated façades in which dimmable lighting controls are used in combination with fenestration, light redirecting strategies (such as light shelves) and dynamic glare control systems (such as automated blinds/shades or dynamic glass) to offset electric lighting with natural daylighting. Dynamic solar control can be achieved conventionally with mechanical moveable louver systems or Venetian blinds integrated into double skin curtainwalls, and such systems are becoming increasingly more popular in Europe. Alternatively, electronically tintable glass (also known as electrochromic or EC glass) can be used to provide variable solar control and can also provide variable glare control as part of the integrated façade. EC glass can, at the touch of a button or command from a building automation system, modulate its solar heat gain coefficient (SHGC) and visible light transmission over a wide range stopping anywhere in between (see Figure 1 for an example of the performance of an EC product). By achieving a visible light transmission as low as 2% in the tinted state, EC glass provides the ability to block uncomfortable glare while maintaining the view to the outside, unlike the mechanical alternatives which block or obstruct the view. The ability to modulate the SHGC also provides the designer with a controllable heat and light valve for their building; the amount of light and heat coming into the space to be tuned depending on the exterior environmental conditions and the needs of the occupants. By dynamically controlling the light and heat flow, significantly more energy savings can be captured than when using a static façade solution as well as providing enhanced occupant comfort with maintained exterior views. In fact, the use of EC glass provides an architect with the ability to design with more glass without energy penalty.

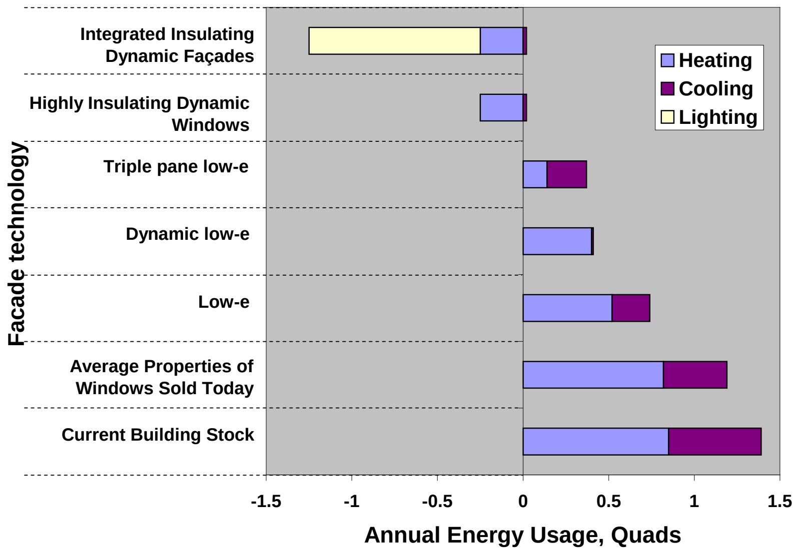

Figure 2: Annual energy usage across the US building stock predicted by LBNL based on the implementation of key façade technologies (Arasteh et al., 2006).

According to the US DOE, the future ZEB commercial window has dynamic solar control with an average U-Factor of 0.1 BTU/hr.^{o}F.ft^{2} (0.57 W/m^{2}-K) and is used as part of an integrated daylighting design [Arasteh, 2006]. In fact, the US DOE estimates that if all windows in commercial buildings in the US were replaced today with highly insulating fenestration with integrated dynamic solar control and daylighting controls, $35B annually could be saved and windows could be turned into energy suppliers of significant measure (*supplying* a positive 1.1 Quads annually compared to today's building stock that *consumes* around 1.4 Quads annually in heating and cooling energy) [Arasteh et. al., 2006]. In fact, by itself, dynamic glass could save 0.8 Quads annually over the current static window baseline (see Figure 2). Dynamic solar control saves energy in all climate zones by providing passive solar gains during heating seasons, minimizing cooling loads during cooling seasons and providing maximum daylight harvesting potential, replacing electric lights with natural light in all seasons.

In this paper we will explore through a series of case studies how dynamic glass can be used to provide architects with a tool that can expand design possibilities for the use of glass and enable the creation of exceptionally energy efficient and comfortable daylit spaces that would otherwise not be possible. We will also demonstrate how EC glass can become an enabler for the use of other sustainable technologies while delivering enhanced building energy efficiency.

ENABLING OTHER SUSTAINABLE DESIGN STRATEGIES: HVAC FREE DESIGN

The first case study is illustrated in Figures 3 and 4 which show exterior and interior images respectively of a two story atrium space at Chabot College Student Services Center in Hayward, California which has been glazed with EC glass. This highly glazed space faces south and west in a cooling dominated climate zone and as such presents significant challenges for glare and heat gain control. Furthermore, as part of the energy efficiency strategy to meet the US Green Building Council's LEED certification, the architect created this atrium as an HVAC-free, naturally ventilated space, implementing a novel natural air cooling and heating strategy. The temperature of the atrium is controlled by radiant heating and cooling in the concrete slab, combined with roof and ceiling air scoops to provide natural air flow. Implementation of EC glass gave the architect sufficient range of solar control that he was able to implement his design strategy without needing to reduce the glazed area in the space. In fact, the architect, Phil Newsome from tBP Architecture, is quoted as saying that the natural ventilation technology implemented in this project would not have been possible without the use of dynamic glass. "This revolutionary dynamic glass controls the amount of sunlight entering the two story space. As a result it has become an architectural enabler that has allowed us to create an HVAC free space." The EC glass is automatically controlled in three zones through the building automation system based on temperature control points with manual over-ride, providing glare control for the occupants of the private office spaces on the second floor as well as a comfortable temperature in the atrium.

FIGURE 3: EC glass installed in the Student Services Center at Chabot College, Hayward, CA (exterior view) which is an example of how EC glass can provide additional design freedom to architects. In this case the use of EC glass enabled the use of a natural ventilation system while maintaining a fully glazed south and west facing atrium.

FIGURE 4: Interior view of the EC glass installed in the Student Services Center at Chabot College, Hayward, CA. The glass can be tinted to control the amount of solar heat entering the space to allow effective use of the natural ventilation system.

The rendering shown in Figure 5 shows Chemeketa Health Sciences Center which has been designed by SRG Partnership and the Energy Studies in Buildings

Laboratory at the University of Oregon to provide a completely daylit two story space with no requirement for electric lighting during the day and with only natural ventilation for cooling. With skylights covering 30% of the roof area achieving a naturally ventilated space was very challenging because of the difficulty of controlling the amount of light and the heat admitted by the glass. However, in this design EC glass is used in the skylights to provide dynamic control over the light and heat entering the space based on the exterior conditions and facilitating the design concept. The unique daylighting design (see Figures 6 and 7) with light reflectors under the skylights provides uniform distribution of the light in to both top and bottom floors and to eliminate “hot spots”. As with the previous example, the use of EC glass in this project has enabled the use of a sustainable design concept that provided for both a fully naturally daylit space without need for mechanical cooling.

FIGURE 5: Rendering of Chemeketa Health Science Center (courtesy of SRG Partnership) which has been designed with 30% skylight area using EC glass to provide a fully daylit and naturally ventilated space.

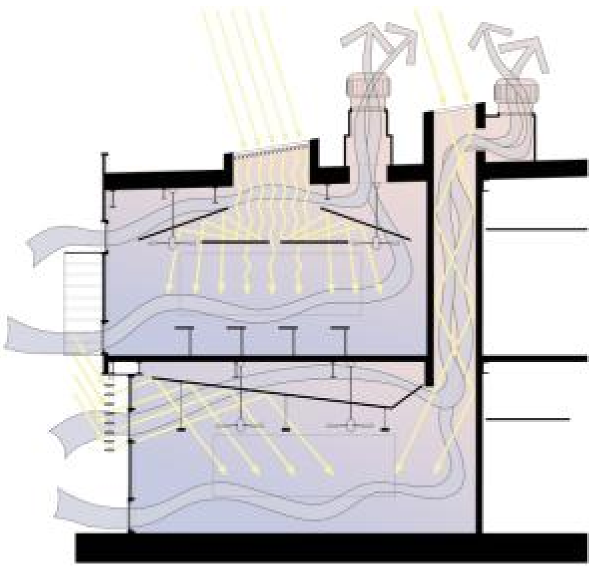

FIGURE 6: Schematic showing the daylighting and natural ventilation design for the two story Chemeketa Health Science building (courtesy of SRG Partnership and Energy Studies in Buildings Laboratory University of Oregon). EC glass is used in the skylights to control the amount of light and heat entering the building.

FIGURE 7: An interior view of one of the skylights with EC glass with the light diffuser underneath in a classroom in the Chemeketa Health Science Center. The use of light redirecting techniques in combination with EC glass allows uniform natural daylight penetration into the building while dynamically controlling for heat and glare.

ENABLING GREATER ARCHITECTURAL FREEDOM

Electronically tintable glass can also provide greater architectural design freedom by allowing the use of glass where otherwise it would be impossible due to too much heat and light admission and the inability to create a comfortable environment. The application shown in Figures 8, 9 and 10 demonstrates this capability. In this project, dynamic glass has been used in a fully glazed roof to create a very open environment, capturing all the benefits of natural daylight, yet controlling unwanted heat gain to create a thermally comfortable environment while at the same time providing the ability to darken the space for audio visual presentations. Dehority Hall at Ball State University in Indiana, USA, features a large skylight (~150 sq.m.) with clerestory glazing around the perimeter. Converted from an open central courtyard into an enclosed space, the university wanted to preserve the open feel of the space and to create a general purpose area serving as a lounge, entryway, and a venue for large group audio visual presentations. Working in the background using light sensors, the dynamic glass solution in this application provides variable levels of tint in order to maintain a constant user-determined light level in the space. This automatic control can be manually over-ridden to, for example, fully tint the glass when darkening the room for presentations or when full glare control is required. There is also a white frit pattern (50% horizontal lines) on the inboard lite that is used to reflect and diffuse upward pointed lights for lighting at night.

When considering solutions for the heat and light control problem that they knew they would have, the architects, Schmidt Associates, investigated alternative options involving mechanical shading solutions. According to the design architect Ryan Benson, EC Glass was a more eco-friendly and aesthetically pleasing alternative to using conventional skylights and architectural controls such as shades, exterior fins or louvers. It enabled him to incorporate more glass into the project without compromising energy efficiency and a view to the natural outdoors. He said “students perform better with daylighting and views. EC Glass was the best option for the Ball State project because it enabled us to maximize natural light and a view to the outdoors, while creating a space that’s thermally and visually comfortable for the students inside”. In addition Gary Canaday, Ball State’s Manager of Campus Construction, Facilities Planning and Management, noted that “we previously had regular glass skylights, but blinding glare and heat was a problem. We looked at installing mechanized shades and blinds, but that option was not attractive and would have created on-going maintenance issues. EC Glass controls the sunlight and heat that enters and leaves the building, reducing our energy use while enhancing and increasing students’ use of the space”. Based on user feedback it is clear that the provision of a comfortable space which met both the “open feel” design intent and the full range of occupant needs would not have been possible without the use of EC glass.

FIGURE 8: Dehority Hall at Ball State University. A fully EC glazed roof with clerestory encloses a courtyard to provide a multiuse space. This image shows the EC glass in the clear state condition with the clerestory in the fully tinted state.

FIGURE 9: Dehority Hall at Ball State University (as in figure 8). The EC glass is in an intermediate state of transmission between fully clear and fully tinted maintaining a set light level in the space.

FIGURE 10: Dehority Hall at Ball State University. In this image, the glass is in the fully tinted state ready to provide the necessary light control for AV presentations.

The fourth case study illustrates how increased design freedom can be provided by using EC glass in a religious facility. Increasingly churches are becoming multi-use spaces and religious services are multi-media in nature. So whilst there is a design desire to bring more natural light into these types of buildings, there is also a need for darkening the space for presentations as well as controlling the heat and glare caused by increased daylight at other times. At Immanuel Bible Church in Virginia the architect implemented EC glass in the large amount of clerestory glazing in order to be able provide as much natural daylight as deep into the building as possible, yet control the heat and, as needed, darken the space for AV presentations (see Figure 11). The panes are controlled in groups (or zones) according to orientation and their height/position on the elevation.

FIGURE 11: Immanuel Bible Church, Springfield, Virginia. EC glass is installed in all the clerestory glazing. In this image, the clerestory at the far end is tinted (the panes on the left hand side are tinted more than those on the right hand side), and the panes in the two tiered clerestories in the foreground are in the fully clear state.

LOUVER FREE FAÇADE DESIGN SOLUTION

The final case study illustrates how EC glass can provide more architectural design freedom and a more elegant façade solution relative to conventional mechanical dynamic solar control alternatives. Figures 12 and 13 show the application of EC glass integrated into a full building façade in the Siemens Wind Turbine Facility in Hutchinson, Kansas, and is the largest installation of EC glass in the world today. The original renderings of this building design showed the use of automatically controlled external horizontal louvers spanning between columnar elements on the façade which were to provide dynamic solar control for the façade. After investigating alternative options, the architects decided to specify electronically tintable glass for a number of reasons. Firstly, on an initial upfront cost basis, the EC solution was less expensive than the mechanical louver system originally envisioned and secondly there would be no additional maintenance costs. Moreover, the EC glass also presented a more elegant façade solution which provided a clean look to the building with unobstructed views to the outside.

The ability to zone the glass on the façade and to variably tint the glass between the fully clear and fully tinted states allows for different control strategies for private offices compared to multi-use spaces such as the cafeteria, entryway and meeting areas. The EC control system is connected via BacNet interface to the Siemens building management system. Based on whether the building is occupied or not, the EC glass can be switched to either optimize for energy efficiency (e.g. fully tinted when in cooling season or fully clear in heating season) or for occupant comfort. When occupied, light sensors in each zone sense the amount of ambient light coming through the EC glass and taking account of the angle of the sun, the lites are then either cleared or tinted in order to achieve the desired ambient light level in the zone. Because of the integration into the building management system, life safety over-rides are also programmed so that the glass is either fully cleared or fully tinted in the event of fire or security events respectively.

Figure 12: Siemens Wind Turbine Facility, Hutchinson, Kansas. The façade design features EC glass for a clean aesthetic, instead of a horizontal mechanical louver system.

FIGURE 13: View from the inside of the Siemens Wind Turbine Facility. The EC façade encloses private and open office space (shown here) as well as communal areas such as the cafeteria in which AV presentations are given during the day utilizing the light dimming capability of EC in lieu of blinds.

CONCLUSION

The five case studies described above clearly demonstrate why EC glass can be considered an architectural enabler. Electronically tintable glass can provide the architect with more design flexibility and the ability to use more glass in the face of ever more stringent building codes as well as facilitating the use of other sustainable technologies which together support the movement towards zero energy buildings.

Electrochromic glazings represent a simple and elegant solution for the control of heat and light incident on the building envelope. Today, even though manufacturing economies of scale are not yet leveraged, EC systems are comparable in cost to, and in an increasing number of cases, lower cost than today's conventional solutions which combine high performance static low-e glass, interior and exterior mechanical shading and larger HVAC capacity. This is especially true when comparing the EC glass solution to automated mechanical shading systems such as exterior louvers, interior automated blinds or double skin curtain wall with integrated automated Venetian blinds. Employing single skin dynamic façades rather than a double skin provides a lot more additional rentable or usable space too. With a static envelope system, the building owner also has the potential reduction in productivity due to comfort issues and worst of all the loss of the primary reason we put windows in a building in the first place – to see out.

Moreover, with the advent of high volume manufacturing scale and the efficiencies afforded by the use of large area magnetron sputtering, the manufacturing costs of the EC glass solution are being driven increasingly lower and lower. In a similar way to the advancement of low-e products over the past 20 years, electronically tintable glass will evolve in terms of price reduction, performance enhancements and breadth of product range, thus driving increasing market adoption until ultimately EC products will become the de-facto standard for building envelopes.

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