Electronically Tintable Glass as an Architectural Enabler

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Abstract

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 daylit 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 [1, 2]. Windows are 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, even with an optimum envelope design to maximize daylighting, 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. 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 decreasing window to wall ratio in new building energy codes and standards through either increasing stringency for insulation values and whole building energy efficiency targets [3] or through additional specific window area limits [4].

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. Too much glass on the west or east elevations, for example, can lead to significant heat gain and glare in the afternoon or morning hours respectively and exterior overhangs or shading are not very effective in addressing this low angle sun. 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 to minimize low angle sun. A static envelope is increasingly becoming a constraint when balancing architectural design with occupant comfort and the increasing demands of energy efficiency.

The US Department of energy has identified three key façade elements required in order to achieve net zero energy commercial buildings [5]: 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 to offset electric lighting with natural daylighting. Dynamic solar control can be achieved conventionally with mechanical moveable louvre 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. EC glass can, at the touch of a button or command from a building automation system, modulate its solar heat gain coefficient (g-value) 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 below 3% in the tinted state, EC glass also 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 solar heat gain coefficient (g-value) 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

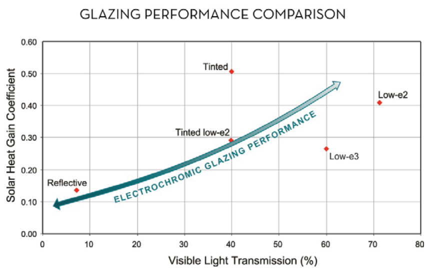

Figure 1: Graph of visible light transmission (Tvis) versus solar heat gain coefficient (SHGC): This chart shows the heat gain and light transmission range of a high performance EC product compared with some examples of standard static glass.

glass without energy penalty.

According to the US DOE, the future ZEB commercial window has dynamic solar control with an average U-Factor of 0.1 BTU/hr.oF.ft2 (0.57 W/m2-K) and is used as part of an integrated daylighting design [5]. 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) [5]. 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.

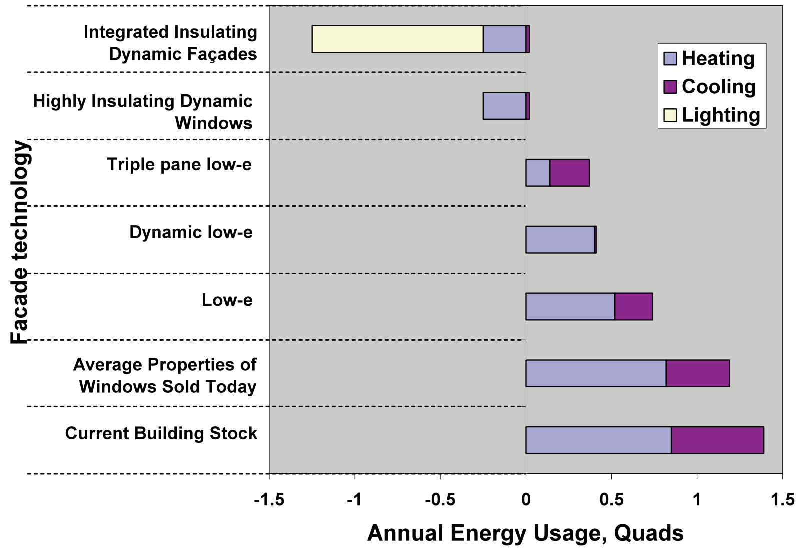

Figure 2: Annual energy usage across the US building stock predicted by LBNL based on the implementation of key façade technologies. From Arasteh et al. Zero Energy Windows, proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings, August 13-18, 2006

Enabling use of other sustainable design strategies

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 for 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.

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 had the potential to be 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 figure 6) with an architect designed "fixture" under the skylights provides uniform distribution of the

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.

light 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 a fully naturally daylit space without need for mechanical cooling. At the time of writing, the EC glass had been installed, but the space had not been commissioned so photographs of the space are not available.

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 because of the inability to create a comfortable environment because of too much heat and light admission. The application shown in Figures 7, 8 and 9 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 investigated alternative options involving mechanical shading solutions and found the electronically tintable glass solution to be both first-cost competitive and more aesthetically appealing, while providing long term energy savings and much lower on-going maintenance requirements. It is clear that the provision of a comfortable space which met the architect's and owner's "open feel" design intent and which was also capable of fulfilling the full range of occupant needs which would not have otherwise been possible.

The fourth 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 10 and 11 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.

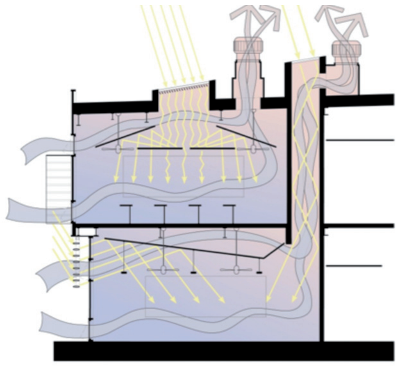

Figure 6: Schematic showing the daylighting and natural ventilation design for the two story Chemeketa Health Science building (courtesy of SRG Partnership and Energy Studies in Buildings Laboratory University of Oregon). EC glass is used in the skylights to control the amount of light and heat entering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

Figure 7: 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 8: Dehority Hall at Ball State University (as in figure 7). 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 9: 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.

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.

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 is 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 overrides are also programmed so that the glass is either fully cleared or fully tinted in the event of fire or security events respectively.

Figure 10: Siemens Wind Turbine Facility, Hutchinson, Kansas. The façade design features EC glass for a clean aesthetic, instead of a horizontal mechanical louvre system.

Figure 11: View from the inside of the Siemens Wind Turbine Facility. The EC glass is in the clear state flooding the interior with natural daylight on a cloudy day.

Conclusion

The four 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 louvres, 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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