Energy Efficient or Healthy Buildings? How Dynamic Glazing Eliminates the Need to Choose.

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ABSTRACT

Creating a high-performance building is as much about energy-efficiency as it is about supporting occupants' health and well-being. Research has shown access to natural daylighting and outdoor views have a positive biological impact and are important to human health; however, we often sacrifice that connection due to the misconception that buildings cannot be both energy efficient and healthy for the people inside. On the other hand, we often design buildings with the occupant in-mind with the intent to bring in daylight and provide outdoor views, but fail to effectively manage heat gain and glare.

In order to achieve comfort, occupants do what they must, leading to the common sight in many commercial buildings of "blinds down, lights on" which leads to poor design performance since much less daylight is admitted and must be augmented with electrical light, views are blocked or obscured and energy use increases.

The gap between "as designed" and "as-built" energy performance has been the subject of recent debate; however, this traditional trade-off between energy performance and delivering sufficient daylight and views, in a managed, comfortable manner no longer needs to hold true. Products are available on the marketplace, like dynamic glass, to provide building occupants with access to natural daylighting and unobstructed views of the outdoors while decreasing the building's reliance on HVAC and overhead electrical systems and increasing the building's overall energy efficiency.

INTRODUCTION

From the very beginning of architecture, man has sought to bring sunlight into his buildings and thus was born the window. For centuries, buildings have been designed in clever ways to maximize the admission of daylight, for that *was* the only source of light. However, in the last century or so, with the advent of electric light, building design has changed to create deeper floor plates and interiors solely lit with electric light. As a result, in the last century access to daylight has declined in our built environment. The popular "cube farm" with office workers toiling for hours at a time in windowless areas has been an all too common feature of our working environment.

The more we understand about the impact of changing daylight patterns on the body's circadian rhythms and the influence of daylight and views on health, well-being and productivity, the more we understand about the importance of daylight in buildings. There is an increasing body of evidence that is demonstrating significant health risks related to the disruption of the circadian rhythms because of lack of daylight exposure at the right time of the

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day or too much of the wrong color light at the wrong times (see for example Blau 2014, Schernhammer et al. 2001, White et. al 2013, Ancoli-Israel et al. 2012). Such risks include:

- Increased risk of obesity
- Increased risk of cancer
- Reduced immune system strength
- Increased risk of heart disease and diabetes
- Increased risk of depression/aggression

A recent study has shown that night shift health care workers suffer from higher rates of obesity, lower fertility, and higher risk of cancer than their day shift counterparts (Schernhammer et al. 2001; Schernhammer 2014). A recent article in the Economist (Blau, 2014) suggested that the epidemic in attention deficit disorder in children could be a result of lack of sleep, caused by circadian rhythm disruption from not enough daylight in the morning and too much screen time (blue light) at night.

Since people are now spending 90% of their day inside buildings, the quality of the built environment is becoming more and more critical to human health.

Green building codes and standards such as BREEAM in the UK, the U.S. Green Building Council's LEED program, which is codified through IES/ANSI/ASHRAE 189.1, and the International Green Construction Code (IgCC), recognize this issue and that a sustainable design is not just about energy efficiency. All of these standards have sections that require the provision of daylight and views to the outside. However, the provision of more daylight can come with unintended consequences to occupants in the form of thermal and visual discomfort. This is often due to too much heat gain and glare coming through the windows since the conventional static building envelope cannot respond to the ever-changing exterior environment.

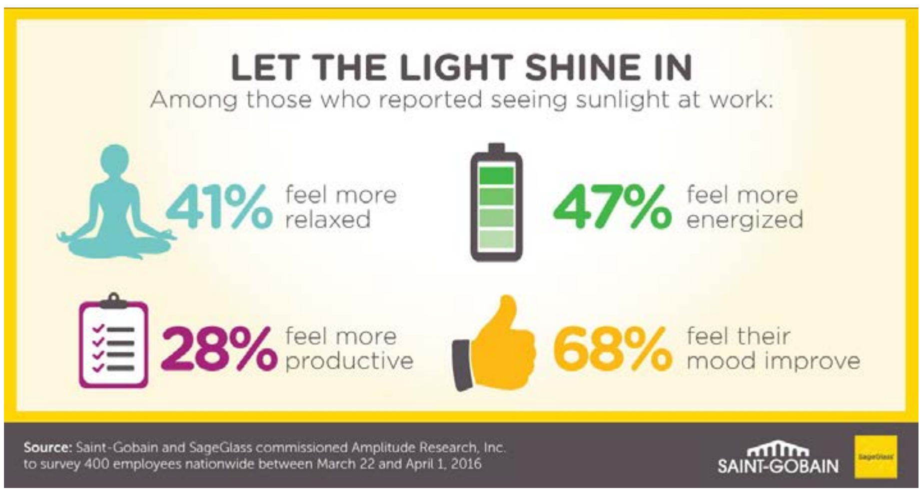
As such, the benefits of access to natural daylight can often be offset by thermally and visually uncomfortable spaces. In the case of glare, occupants pull blinds and shades and then block the admission of daylight and the view to the outside, negating the benefits of daylighting and views. The use of manual blinds also causes the building energy use to go up compared to the design loads because of the increased use of electrical lighting to compensate for the fact that the blinds remain drawn long after the glare condition has gone.

Indeed, in recent years, it has come to light that a number of green certified buildings are actually not any more energy efficient than their non-green designed counterparts. This has led to the initiation of energy performance verification requirements of the as-built designs.

FIGURE 1: A pictorial representation of the Green Building Challenge. How to optimize both energy efficiency and daylight and views without compromising occupant comfort.

In parallel, the push for increased energy performance in buildings has also given rise to significant debate about the role of windows, and more importantly, the amount of glass that should be used (Wilson 2010; Shuttleworth 2008). Windows are often seen as the weak link in a building because of their lower insulation performance and higher solar heat gain compared to a solid wall. Indeed, in both Europe and North America we are seeing an increasing trend to reduced window area in new building codes through increasing stringency of insulation values and whole building energy efficiency targets (Part L of the Building Regulations in the UK), or through specific window area limits as in the International Energy Conservation Code (IECC) 2012. These trends are also being mirrored in the green codes as demonstrated very recently by the highly public debate over the proposed reduction in the allowable window area from 40% to 30% in the prescriptive path of ASHRAE 189.1 (Devlin 2014; Sanders 2014). After significant pushback from the daylight design and research community as well as the glass industry it was withdrawn, but the debate continues.

The window to wall ratio debate within the green codes especially is leading to a dichotomy between providing acceptable window area for daylighting and views and achieving energy efficiency targets, all while providing occupant visual and thermal comfort. This is a major challenge for "green building" design as is pictorially represented in Figure 1.



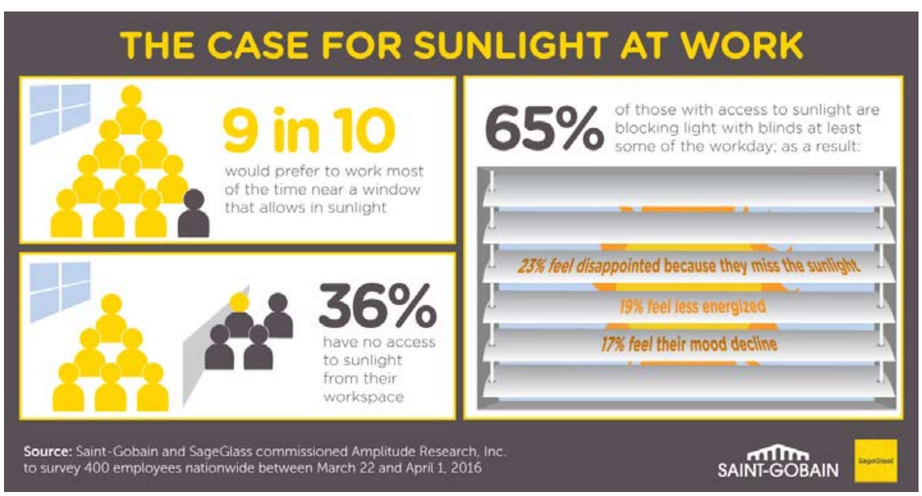


FIGURE 2: Visual representations of the findings from a partnered study between Saint-Gobain and SageGlass about the role of daylight in workplace productivity.

AN ELEGANT SOLUTION

Electrochromic (EC) glass, which can, at the touch of a button, with a swipe in a mobile application, or with a higher level command from a building automation system, modulate its solar heat gain coefficient (SHGC) and visible light transmission over a wide range, stopping at points in between (e.g. a range of 60% to 1% in visible light transmission and 0.41 to 0.09 in SHGC), can provide an elegant solution to this problem (see figure 3). EC glass 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 the use of electric lights with natural light in all seasons. Additionally, because products today can achieve transmissions of 1%T or less, they can control glare without using blinds, thus preserving the view and connection with the outside in contrast to mechanical alternatives, which block or mar the view. Studies have shown that 1%T is required to be able to control the glare (LBNL 2006; Kelly et al. 2013).

FIGURE 3: Graph of visible light transmission (T_{vis}) versus solar heat gain coefficient (SHGC) which demonstrates the heat gain and light transmission range of a high performance EC product compared with examples of standard static glass.

EC coatings can be cleanly integrated into a double or triple glazing unit just like traditional coatings (see Figure 4) and different exterior aesthetics can be achieved by adding tints or another coating to the exterior glass pane. The ability to modulate the sun's light and heat provides the designer with a controllable heat and light valve for their building; the amount of light and heat coming into the space is 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 whilst maintaining exterior views. As a result, the use of EC glass provides an architect with the ability to design with more glass, thus providing the needed access to daylight and views, without energy or comfort penalty.

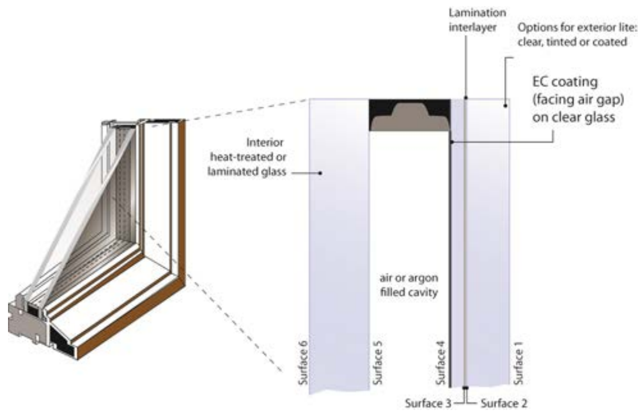


FIGURE 4: An electrochromic insulating glass unit.

DESIGN FLEXIBILITY WITHOUT ENERGY PENALTY

MORE GLASS WITHOUT ENERGY PENALTY

Because of the ability to dynamically control the heat flows into a building, EC glass can provide additional architectural freedom because more glass can be used, especially on challenging façades, without energy penalty. For example, modeling work completed recently by Professor Rick Mistrick (Mistrick 2014) at Pennsylvania State University demonstrates that the standard prototypical medium size office building used by PNNL to measure the performance of ASHRAE Standard 90.1 uses less energy in Phoenix when glazed with a 50% window to wall ratio (WWR) of EC than with a 30% WWR of code compliant static glazing (see Figure 5). When manual blind use is considered, which reduces the energy saved from daylight harvesting, the 50% WWR EC building uses less energy than one at 25% WWR with code compliant glazing. Note that this prototypical building does not have a good daylighting design and so it does not show the expected optimum profile where the building energy would go down as WWR increases initially because the conductive losses and heat gains are offset by electrical lighting energy savings from daylight harvesting. It is also core load dominated, so the impact of the perimeter is relatively small compared to the core.

MINIMIZING THE IMPACT OF ORIENTATION

Also, using EC glazing can help minimize the impact of orientation. The optimum orientation for buildings is to put the long axes facing north and south, so as to minimize glazing on the east and west elevations where the sun angle is low and more difficult to shade. However, sometimes the site and other factors do not allow for the "perfect" orientation, and EC glass can help minimize this impact. Figure 6 shows the results of energy modeling by Prof. Mistrick (Mistrick 2014) on the same PNNL prototypical medium sized office building discussed above as a function of orientation in Phoenix. The energy increase associated with turning the building 45 degrees away from the optimum is much smaller for the EC than with the static glazing systems.

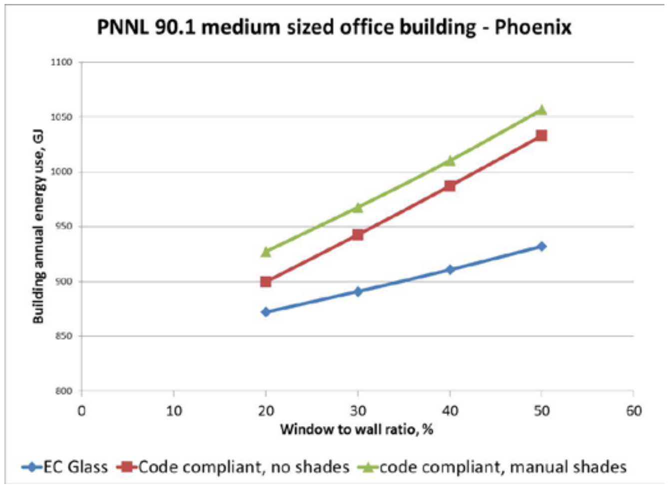


FIGURE 5: The building energy as a function of window to wall ratio for a prototypical medium sized office building in Phoenix for EC glass, code compliant glazing and code compliant glazing with manual blinds in use for glare control.

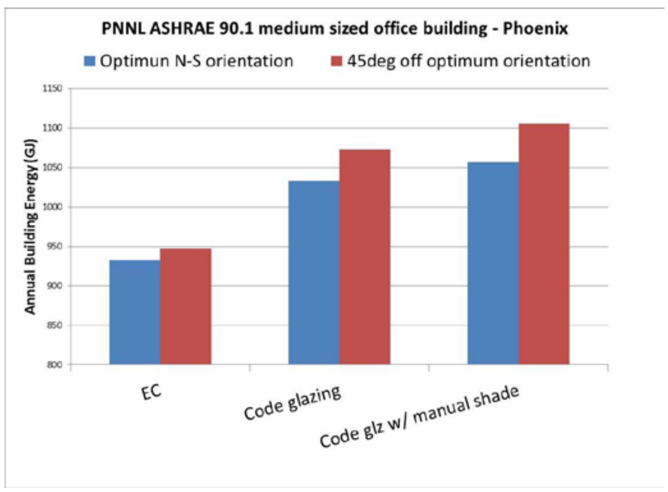


FIGURE 6: The building energy as a function of orientation for a prototypical medium sized office building in Phoenix using EC glass, code compliant glass and code compliant glass with manual shading all at 50% window to wall ratio (WWR).

LIGHT COLOR QUALITY

Thermal comfort and glare control are not the only aspects of the human comfort equation. The color of the light in a room is important to color rendering of objects and on occupant acceptance as has been seen over the years with compact florescent (CFL) light bulbs, the best of which have a color rendering index (CRI) of around 80-85, but many have had color rendering indices much lower and has led to market acceptance problems. The color rendering index is a measure of how close the color of light is to the reference "sunlight" spectrum, which is given a value of 100. Figure 7 shows the spectral power distributions and respective CRIs of a number of different light sources.

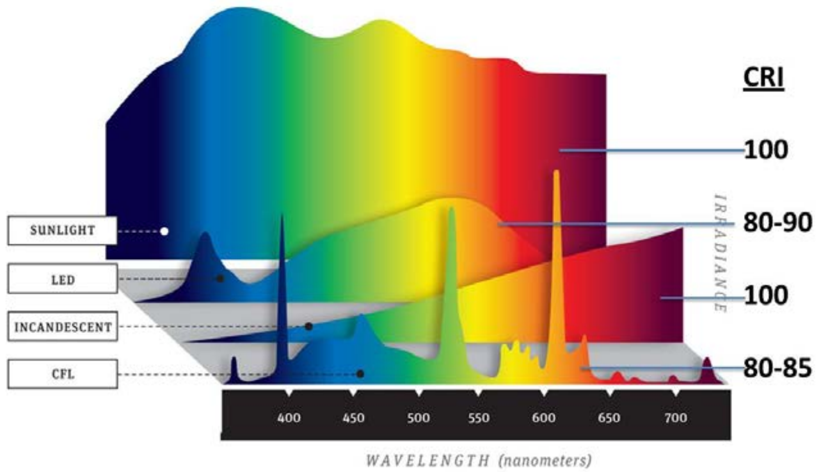


FIGURE 7: Spectral power distributions in the visible light range for various light sources and their respective color rendering indices.

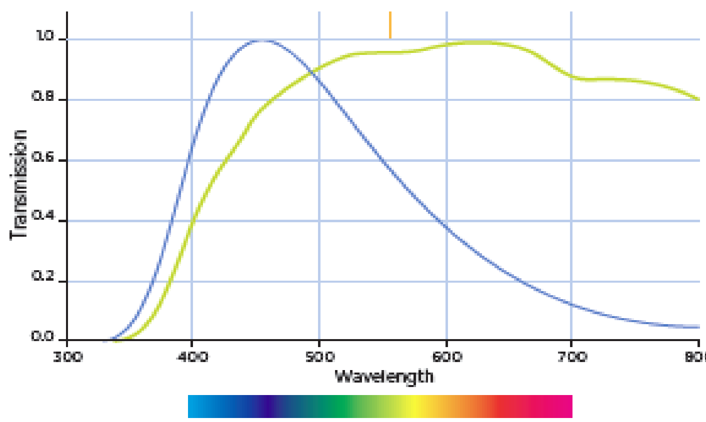


FIGURE 8: The transmission spectra of light coming through EC glass in the fully clear (green line) and the fully tinted (blue line) states.

Since EC glass generally tints to a blue-gray color, and previous studies have found that the color rendition of fixed tinted blue glass has caused problems for occupants (Arsenault et al. 2012), the color quality of spaces glazed with EC glass is important to understand. Studies by John Mardaljevic (University of Loughborough, UK), (Mardaljevic et al 2014; Mardaljevic 2014) has confirmed the empirical observation that the light in spaces glazed with EC glass is essentially the same as in spaces glazed with clear glass as long as a small proportion of the glass is kept in the highest transmittance state. Figure 8 illustrates the spectral power density of the light coming through EC glass in its fully clear and fully tinted states respectively. Note that the clear state power density is very flat across the visible range, which suggests relatively neutral like the spectrum of sunlight in Figure 7. Note that the spectrum of sunlight and daylight changes through the day – starting off more blue in the morning and ending up more red at the end of the day, so even the spectrum of daylight is not static or neutral per se. The color of light coming through the EC in the tinted state is clearly blue, as shown by the peak at around 450nm.

Figure 9 shows schematically how light is combined in the space when transmitted through a façade where the majority of the glass (8 out of 9 panes) is in the fully tinted state and a small amount (1 of 9 panes) is in the clear state. As can be seen, with the clear state at 60% visible light transmission and the tinted state at 1%T, the bulk of the light transmitted is coming through the single pane in the clear state. As a result, the light in the room is dominated by the color of the clear state (about 90% of the light) which is essentially neutral. The resultant spectral power densities of light coming through this, and other combinations of EC panes, are shown in Figure 10.

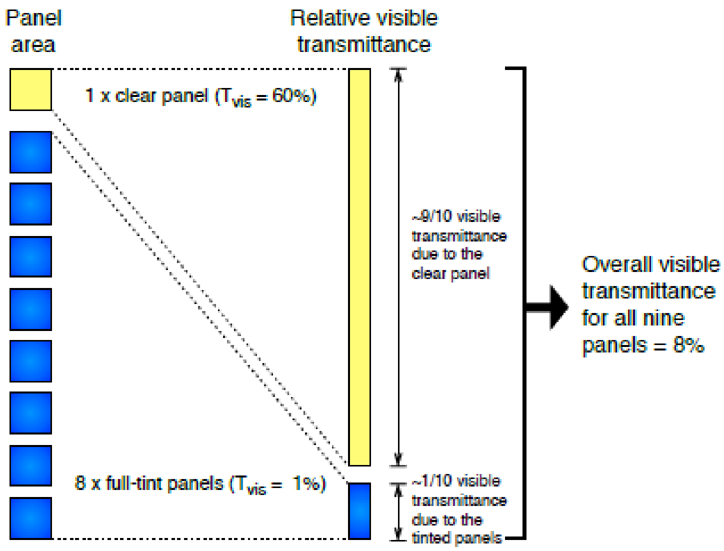


FIGURE 9: Combination of one EC pane set to clear and eight set to full-tint. The bulk of the visible transmittance is that due to clear glass, resulting in neutral daylight dominating the illumination of the space (Mardaljevic, 2014).

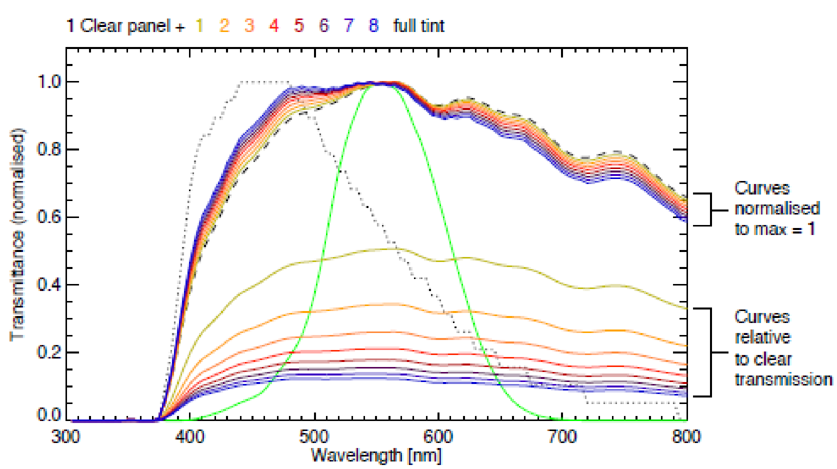


FIGURE 10: The calculated spectral power density of the resultant light coming through a combination of 1 clear EC pane and 1 to 8 fully tinted panes (giving ratios of clear: tint areas of 1:1 up to 1:8). The upper curves are normalized in order to be able to better compare them. The lower curves are un-normalized, and demonstrate the commensurate reduction in absolute light intensity as a higher proportion of panes are tinted. The green curve is the human photopic response, which is peaked in the green (Mardaljevic 2014).

Figure 11 illustrates actual measured spectral power density (SPD) of the light in an office glazed with EC glass at six points in the room – facing the windows, facing the wall opposite the windows, in the four positions where the occupants sit in the office, and compares it to the calculated values based on assuming a 5500K daylight source. As you can see, the spectra demonstrate that the color of the light is essentially neutral at all positions in the room, even when facing the window and match the theory well. Also the average of the measured color rendering index of the light in the space was 93 which is generally accepted good color rendering.

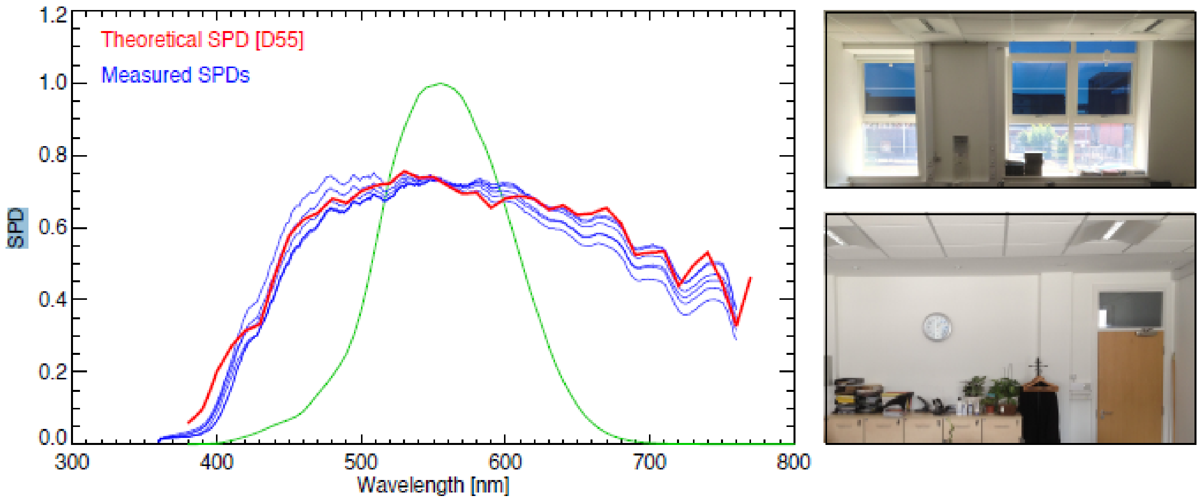


FIGURE 11: The measured (blue) and calculated (red) light spectral power density in a real office space glazed with EC glass (Mardaljevic, 2014). The six points measured were facing the window, facing the wall opposite (as shown in the images to the right of the figure) plus four points where the occupants sit.

ELECTROCHROMIC GLASS DESIGN AND PERFORMANCE ENHANCEMENTS

Electrochromic (EC) glazing, which has been commercially available for more than ten years since its initial introduction, has undergone significant developments most of which have occurred in the last couple of years. These developments have provided increased flexibility for designers and reduced the trade-off architects have had to make between building performance and the design aesthetic. The most important of these improvements include increased size availability (up to 5'x10'), increased manufacturing volumes, greater selection of geometric shapes, availability of a range of colors and improved reflection characteristics that architects can choose from to match their project color aesthetic (see Figure 12), and the ability to control up to three different areas of a single EC pane as different segments (see Figure 13). Finally, the addition of software user interfaces (mobile app) to complement the physical wall switch for manual control allows less hardware-intensive interior design while still being able to manually control an increasing number of possible zones.

FIGURE 12: Examples of different exterior color aesthetics in EC glazing now available for designers to complement the designer's color palette for the building.left to bottom right – Classic, Gray, Green and Blue).

FIGURE 13: Example of the improved exterior aesthetic of the standard EC product on clear glass. Left column: First generation (GEN 1) product in clear (top image) and tinted (lower) states. Right column: New generation (GEN 2) EC in clear (top) and tinted (bottom) states.

FIGURE 14: An example of one of the new advances in EC glazing: In-pane zoning. This figure shows an EC product installed in a building with the top of each pane in a tinted state and the bottom of the pane in a higher transmittance state. Photo courtesy of Jeffrey Totaro.

The in-pane zoning feature is essential in floor to ceiling glass to provide for effective co-optimization of glare control, light color quality, daylight admission and energy performance. For effective glare control, the EC glass needs to be tintable to 1% visible light transmittance, yet if the whole façade is at 1%T, there will be insufficient daylight admission, the lights will have to be turned on and the light color quality will suffer. With the ability to zone the EC within a pane, optimized performance across multiple parameters can be achieved as well as the architect's goal of reducing the number of mullions in the framing system.

The following case studies demonstrate how dynamic glass can be used to provide architects with a tool that can expand design possibilities for the use of glass and allow for optimum daylighting and views while compromising neither energy efficiency nor occupant comfort.

CASE STUDIES

ICONIC GLASS DESIGN

Architects are more and more frequently designing prominent buildings or iconic spaces utilizing all glass. While providing a visually striking and modern aesthetic, ensuring both energy efficiency and occupant thermal and visual comfort is a challenge, especially in harsh climates. An example of how electrochromic glazing can meet this challenge is demonstrated in Figure 15 which shows EC glass implemented in Bowie State University's new Center for Natural Sciences, Mathematics and Nursing, designed by architects at Perkins + Will. When creating this new facility, the University strove to ensure the design provided "an optimum environment for students and faculty to engage in transformative interdisciplinary learning and instruction." Preserving the views within the building's open design was of paramount concern, especially as the location did not offer any shade. Thus, mechanical blinds and exterior shades didn't meet the needs of the client.

FIGURE 15: Interior and exterior views of the Center for Natural Sciences, Mathematics and Nursing at Bowie State University in Bowie, Maryland. The Beacon, a three-story cylindrical meeting area is shown here in different tint zones demonstrating how students and staff can experience the ideal balance between comfort and daylight.

Bowie State and architects Perkins + Will found the ideal solution by incorporating more than 25,000 square feet of electronically tintable glazing into the Center for Natural Sciences, Mathematics and Nursing, including a large south-facing curtain wall. The EC glass dynamically controls sunlight to optimize daylighting, outdoor views and interior comfort while preventing glare, fading and overheating. This helps create a more comfortable, productive learning environment conducive to collaboration and inspiration. The dynamic glass tints on-demand, allowing professors to customize solar control for individual classrooms and labs. It also tints automatically to block sunlight on hot days and dramatically reduce energy demand in the building. Bowie State students and faculty throughout the 149,000-square-foot facility are now able to work together free from heat gain and glare in a fully daylit environment with clear exterior views.

A second example of an iconic glass design using EC glass is shown in Figure 16.

The U.S. Bank Tower in Los Angeles is the tallest building in the western United States. For renowned restaurateur Emil Eyvazoff, this iconic skyscraper was the perfect spot for 71Above, a premier restaurant located on the 71st floor that features breathtaking, 360-degree views of the city. To realize his vision, however, Eyvazoff needed to manage the glare and solar heat gain resulting from the intense, year-round southern California sunshine, but in a way that would not block the views.

Together, owner Eyvazoff and Tag Front selected electrochromic glazing to solve the problem. Electronically tintable glass controls sunlight to optimize daylight, outdoor views and comfort while preventing glare, fading and overheating – all without the need for blinds or shades. By dynamically controlling sunlight and managing heat gain, EC glass allows for unobstructed views and a comfortable dining experience at any time. 71Above features nearly 3,000 square feet of EC glazing around its perimeter. Now, 71Above staff can easily control the environment to create a consistently comfortable experience that visually connects patrons to the city below.

Note how the color rendering in the space looks neutral because of the combination of panes in the clear state and panes in the tinted state.

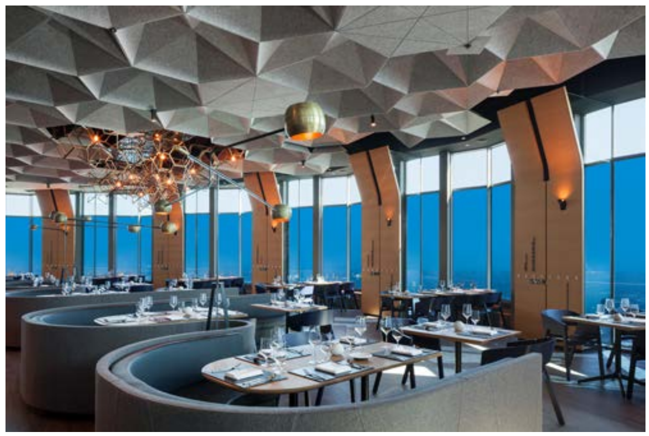


FIGURE 16: EC glass installed in at 71Above within the U.S. Bank Tower skyscraper in Los Angeles, California.

GREEN HEALTH CARE

Improved daylight admission and views to nature have been shown to increase recovery rates of patients in hospitals and reduce the use of pain medication (see, for example, the foundational study by Ulrich in 1984 (Ulrich 1984) and a summary of the literature developed by Velikov and Janiski commissioned by Guardian Industries (Velikov and Janiski 2012). Also, when infection control is so important, the elimination of blinds, which can harbor dirt, dust and bacteria, is another key benefit for EC in healthcare applications – allowing comfortable daylighting and views with improved infection control. Figure 17 shows some images of a healthcare application at Butler County Medical Center in Nebraska where EC glass has been used to provide an open-air feel and an expansive view of the park and golf course for the occupants of the new wellness center. The wellness center features a unique, curved south-facing glass curtain wall that offers beautiful views of the park and golf course. Due to the complex curvature of the curtain wall and non-rectangular shapes, mechanical shades would have been problematic not just because of infection control.

FIGURE 17: Images of Butler County Health Care Facility, Nebraska.

ENERGY EFFICIENT HISTORIC PRESERVATION

Figure 18 illustrates another application for EC glass where energy saving performance is a requirement along with daylighting, as well as preservation of the historic building appearance.

Hotel Monaco DC is located in the heart of Washington, D.C., across the street from the Smithsonian Institution and situated amidst the historic General Post Office built in 1839. The hotel set out to make a bold, one-of-a-kind architectural statement with a new onsite location for Dirty Habit, the second installment of a popular restaurant in San Francisco.

Since the General Post Office is a National Historic Landmark, the new space was required by law to preserve visibility to the post office's classical revival façade, which would mean incorporating significant structural glass. Architects were tasked to find a way to control glare and heat gain inside while maximizing the views outside. The HVAC system on the roof also had to be as lightweight as possible to ensure an all-glass wall system could support it.

FIGURE 18: When the electrochromic glass is clear, the view from the surrounding patio into the front of the Dirty Habit reveals an exciting interior design. On hot, sunny days, the dynamic glass is darkened to keep diners comfortable inside. This view of the rear of the Dirty Habit shows the reflected building across the patio.

The project team was pleased to discover that electronically tintable glazing resolved every design challenge it faced.

Covering 2,042 square feet across the entire restaurant façade and a skylight, EC glass automatically darkens or clears in response to sun movement throughout the day. Glare and solar heat gain are controlled inside the restaurant at all times to keep diners comfortable and the view unobstructed, complying with the requirements set forth by the historical preservation committee. The resulting reductions in cooling requirements also allowed a more compact and lightweight HVAC system to be installed on the roof.

CONCLUSIONS

The impact of being able to design with more glass without energy or comfort penalty should not be underestimated. Glass is a key architectural design tool and provides significant design flexibility for architects. Sustainable design standards and codes recognize the need to use glass to provide occupants with access to daylight and views, because of the positive impact that it has on people's health and well-being, yet doing so often requires compromising energy performance and at times occupant thermal and visual comfort. Dynamic glazing can relieve the constraints enforced on designers by static building envelopes when balancing architectural design with occupant comfort and energy efficiency. The improvements in EC glass aesthetics and functionality described herein and the case studies clearly demonstrate that EC glass can provide an elegant façade solution which achieves both the competing goals of strong energy performance and access to daylight and views, without compromising occupant thermal and visual comfort or the aesthetics of the façade design. The ability to maintain architectural design freedom while still providing an energy efficient AND comfortable building is invaluable. This value will continue to increase as energy efficiency targets rise and as the importance of creating people friendly workspaces is further appreciated.

ACKNOWLEDGEMENTS

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