Smart Glazing Systems for Low Energy Architecture

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Abstract

The industrial and technological development in the twentieth century caused the increased emissions and heat, thus increasing the temperature of the Earth's climate.

The increase in temperature of the Earth's climate led to a negative impact on energy consumption. That caused increasing rates of energy consumption to overcome the high temperature change. So, the researchers concerned since the twentieth century; with minimising energy consumption by developing smart materials that were used in the construction and finishing of buildings to save energy consumption.

Smart materials in architectural definition is high technological materials that when placed in a building they respond intelligently with the climatic change, with different seasons either the environment is hot or cold to comfort or to get the human needs.

This research aims to introduce one of smart materials; smart glass which was used in the construction and finishing of buildings and the different benefits in terms of: saving energy, comfort for users of the building, raising the efficiency of production and maximising the technical performance.

Keywords: *Smart Glass, Energy Consumption, Modern Technology Materials, Daylighting.*

1 Introduction

The last few years have witnessed gradual increase in environmental problems. Global warming due to the increase of carbon dioxide emission was one of the major problems that appeared and threatened our environment in many aspects. Buildings account for about 43% of carbon dioxide emissions that cause the gradual increase of global warming. Recently architecture tried to find smart solutions to overcome these environmental hazards and problems specially those concerning energy consumption. One of these smart solutions was inventing smart glazing systems that help in the process of energy control inside buildings. Smart materials are emerging in technology with numerous potential applications in industries as diverse as consumer, sporting, medical and dental, computer, telecommunications, manufacturing, automotive, aerospace, as well as civil and structural engineering.

Smart glazing systems, similar to living beings, have the ability to perform both sensing and actuating functions and are capable of adapting to changes in the environment. In other words, smart glazing systems can change themselves in response to an outside stimulus or respond to the stimulus by producing a signal of some sort. Hence, smart glazing systems can be used as "sensors", "actuators" or in some cases as "self-sensing actuators" in general. By utilizing these materials, a complicated part in a system consisting of individual structural, sensing and actuating components can now exist in a single component, thereby reducing overall size and complexity of the system. However, smart materials will never replace system fully; they are usually part of some smart systems.

2 Buildings and Energy Consumption

We are living in a critical time. Energy security and climate change are two of the most important challenges of our lifetimes, and need urgent attention. The decisions we make and the paths we take now will determine the future health, security and well being of our Nation and the world. It is clear that there is no single solution to the problem. The challenge is so massive and urgent that it requires multiple simultaneous responses and solutions. Reducing energy consumption in buildings by using smart material must be part of the solution.

The great increase of the carbon dioxide emission in the last years as shown in (figure 1) caused the greenhouse gas (GHG) effect, which has a direct impact on environment and energy consumption. Buildings are number one in global CO2 emissions as shown in (figure 2). In the United States, people spend an average of 90% of their lives in buildings. Buildings are an important target of the clean technology movement. According to the U.S. Green Building Council, buildings in the United States account for 39% of energy use, 71% of electricity consumption, 40% of non-industrial waste and 38% of carbon dioxide emissions (USGBC Research Committee, 2008).

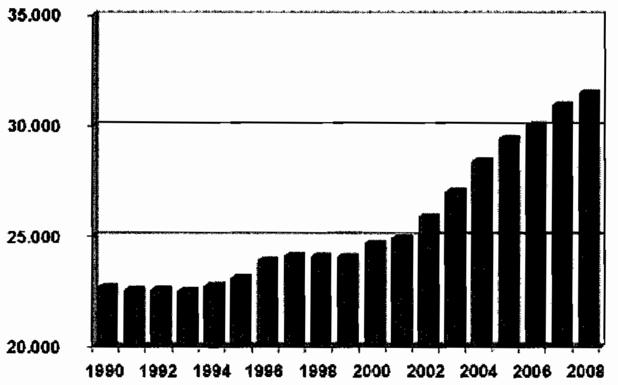

Figure. (1): Showing the increase of global CO2-Emissions [Mio.t].

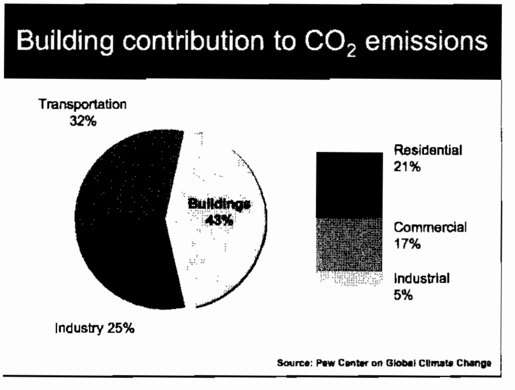

Figure. (2): Showing the amount of co2 emissions comes from buildings.

Also, the World Energy Report 2004 declared that the world energy demand will rise by 60% by 2030 with two thirds of the additional needs will come from developing countries (World Energy Report, 2004).

Buildings use energy for heating, cooling and lighting, add to the problems of exhaustion of fossil fuel supplies and environmental pollution. In order to make buildings more energy-efficient an extensive set of "energy-saving building components" has been developed that contributes to minimize the energy need of buildings, that helps buildings to access renewable energy sources, and that helps buildings to utilize fossil fuels as efficiently as possible. Examples of such energy saving building components are advanced glazing systems, thermal insulation layers, photovoltaic etc.

In general, buildings use energy in two different ways: first type is known as Envelope Load Dominated Building (ELDB) such as houses; and the second, Internally Load Dominated Building (ILDB) such as offices, schools, libraries, airports and stores (Ternoey S.E., 1999). The bulk of energy uses in the ELDB are lights, appliances and hot water whereas, ILDB mainly lights, computers, photocopying machines and air-conditioning. In offices, the artificial lighting accounts for about 50% of the total energy use and a significant portion of the energy utilized in other non-residential buildings.

So, by following a careful design and choice of smart materials, it is possible to produce buildings that use substantially less energy without compromising occupant comfort or the building's functionality. Whole-building design considers the energy-related impacts and interactions of all building components, including the building site; its envelope (walls, windows, doors, and roof); its heating, ventilation, and air-conditioning (HVAC) system; and its lighting, controls, and equipment.

Finally, by actively managing lighting and cooling, smart glass in windows could reduce peak electric loads by 20–30 percent in many commercial buildings, increase daylighting benefits, improve comfort, and potentially enhance productivity in homes and offices. These technologies can provide maximum flexibility in aggressively managing demand and energy use in buildings in the emerging deregulated utility environment. They can also move the building community towards a goal of producing advanced buildings with minimal impact on the nation's energy resources.

3 Daylighting

There are few conditions in the history of humankind as pervasive as the need for natural light and the desire to control it. Daylighting involves the purposeful introduction of natural light, also known as daylight, into the interior of a building.

Varying perspectives on daylighting exist within this broad context. In a study of mostly North American and Australian design professionals, an architectural definition of daylighting that involves "the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment" was deemed the most relevant. However, daylighting definitions pertaining to other orientations such as lighting energy savings and building energy consumption also were considered relevant to some (Reinhart C.F., Mardaljevic J. & Rogers Z., 2006).

The strategic application of daylighting primarily involves shading from the sun, protection from glare and the redirection of natural light (International Energy Agency, 2000). Studies examining the effect of daylighting strategies signal both economic and human benefit. Properly designed daylighting systems in retail, educational and workplace settings have been associated with dramatic increases in individual well being and productivity.

The sun provides bountiful energy. Harvesting this energy through daylighting strategies offers the opportunity to reduce the use of interior electric lighting, lower heating and cooling costs, increase occupant well being and health, and minimize environmental impact (Loveland J., 2003). Driven by a combination of energy efficiency goals and human well being desires, demand for daylighting solutions is growing. Some of these solutions are passive in nature and involve decisions as fundamental as the sitting of a building or the size and placement of conventional windows. Others are of a more active nature, integrating daylighting products and processes with computerized building control systems. Effective use of both active and passive solutions will help to advance the sustainability of buildings (Collins B.L.)

According to the U.S. Department of Energy (DOE). The DOE projects energy costs in U.S. buildings to exceed $400 billion in 2010. Windows are central elements of a building's design. They contribute aesthetically and support occupant comfort by introducing natural light and preserving views. "Smart glass" gives users the ability to "tune" the amount of light, glare and heat passing through windows, skylights, doors and other fenestration products.

Daylighting is a technical term given to a common centuries-old, geography and culture independent design basic by 20th century architects, many of whom who had made inadequate use of the design due to low cost and ignorance of global warming issues.

The benefits of considering architectural daylighting:

Utilization of natural light entering the interior of a building to:

- Reduce energy used for artificial lighting (US DOE Goal: By 2025, 50% reduction in the energy used to illuminate buildings).
- Lower heating and cooling costs.
- Increase occupant well being and productivity.
- Decrease environmental impact.

4 Smart Materials and Smart Glass

The Encyclopedia of Chemical Technology defines smart materials as objects that sense environmental events, process that sensory information, and then act on the environment. The second definition refers to materials as a series of actions. Smart materials in architectural definition is high technological materials that when placed in a building they respond intelligently with the climatic change, with different seasons (summer and winter) either the environment is hot or cold to comfort or to get the human needs. (M. Addington, D. L. Schodek, 2005)

The term „Smart Material" is applicable to materials and systems that can responsively react to changing environments through material properties or material synthesis. Their interactions stem from physical and/or chemical influences, such as change in temperature, pressure or exposure to radiation, magnetic or electric fields. One of the most important smart materials used in buildings is smart glass.

4.1 Overview of smart glass

Smart glass is a category of glazing materials that changes its light-control properties in reaction to an external stimulus (Sottile G.M., 2007), known also as switchable glazing. Smart glass is a relatively new category of high performing glazing with significant clean technology characteristics. It can be used in a wide range of everyday products such as windows, doors, skylights, partitions, sunroofs, sun visors and more. Expectations for growth in smart glass demand are very high (Sottile G.M., 2008).

Smart Glass can be manually or automatically "tuned" to precisely control the amount of light, glare and heat passing through a window. While glass is a favoured product for use in building facades; glare, solar heat gain and UV exposure are problematic and can often make the use of glass impractical resulting in the need to invest in expensive solar shading devices. Glass facades using smart glass technology reducing the need for air conditioning during the summer months and heating during winter. The ability to instantly switch the glass to maximize daylight when it's really needed and to provide controllable solar shading during peak light conditions is valuable and unique.

4.1 Types of smart glass

4.1.1 Passive smart glass

Does not involve an electrical stimulus. Rather, it reacts to the presence of other stimuli such as light (Photochromic Glass) or heat (Thermochromic Glass).

Photochromic Glass (PC)

That changes color when exposed to light, Photochromic materials absorb radiant energy which causes a reversible change of a single chemical species between two different energy states, both of which have different absorption spectra. Photochromic materials absorb electromagnetic energy in the ultraviolet region to produce an intrinsic property change (Farghaly Yasser, 2009). Depending on the incident energy, the material switches between the reflectively and absorptively selective parts of the visible spectrum (figure 3).

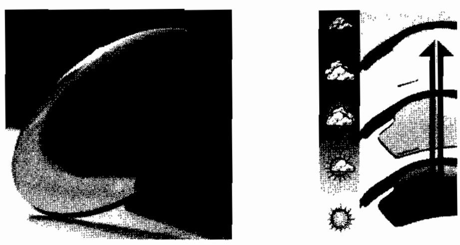

Figure. (3): Sample of uses of Photochromic Glass

Thermo chromic Glass (TC)

Thermo chromic materials change colour due to temperature changes. It absorbs heat, which leads to a thermally induced chemical reaction or phase transformation. They have properties that undergo reversible changes when the surrounding temperature is changed (figure 4).

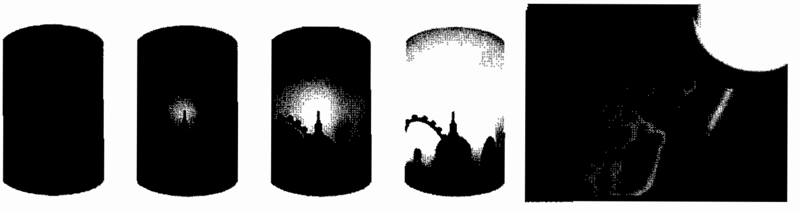

Figure (4): Shows the effect of thermal heat on Glass

4.1.2 Active smart glass

Active smart glass named also switchable glass that changes light transmission properties when voltage is applied. Active smart glass is now being offered as an innovative design solution for products ranging from aerospace windows to architectural skylights and automotive sunroofs.

Certain types of smart glass can allow users to control the amount of light and heat passing through: with the press of a button, it changes from transparent to opaque, partially blocking light while maintaining a clear view of what lies behind the window. Another type of smart glass can provide privacy at the turn of a switch.

There are three primary types of active smart glass technologies, each with its own unique chemistry, production requirements and performance characteristics; electro-chromic devices(EC), suspended particle devices (SPD), and Polymer dispersed liquid crystal devices (PDLC).

These technologies are not one-constituent materials, but consist of multi-layer assemblies of different materials working together.

Electro chromic devices (EC)

Electro chromic windows center around special materials that have electro chromic properties. "Electro chromic" describes materials that can change colour when energized by an electrical current. Essentially, electricity kicks off a chemical reaction in this sort of material. This reaction (like any chemical reaction) changes the properties of the material. In this case, the reaction changes the way the material reflects and absorbs light. In some electro chromic materials, the change is between different colors. In electrochromic windows, the material changes between colored (reflecting light of some color) and transparent (not reflecting any light).

Electrochromic glass provides visibility even in the darkened state and thus preserves visible contact with the outside environment. It has been used in small-scale applications such as rearview mirrors. Electrochromic technology also finds use in indoor applications, for example, for protection of objects under the glass of museum display cases and picture frame glass from the damaging effects of the UV and visible wavelengths of artificial light.

Electrochromic windows darken when voltage is added and are transparent when voltage is taken away. Electrochromic windows can be adjusted to allow varying levels of visibility.

Like other smart windows, electrochromic windows are made by sandwiching certain materials between two panes of glass. It consists of layers in order from inside to outside as shown in (fig. 5,6):

- Glass or plastic panel
- Conducting oxide
- Electrochromic layer, such as tungsten oxide
- Ion conductor/electrolyte
- Ion storage
- A second layer of conducting oxide
- A second glass or plastic panel

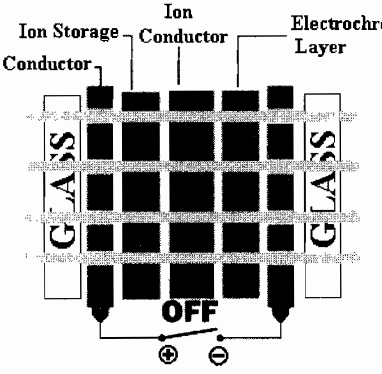

Figure. (5): When switched off, an electro chromic window remains transparent.

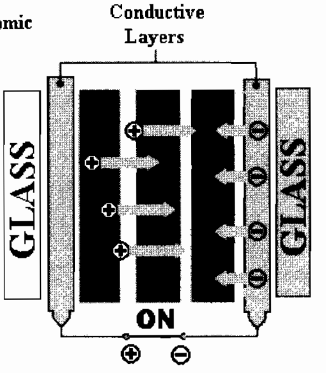

Figure. (6): Shows When switched on, a low volt of electricity makes the electro chromic window translucent.

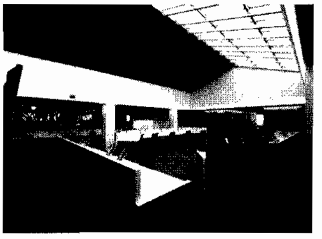

Figure. (7): Electro chromic glass used in sky light in office building

Suspended Particle Devices (SPD)

In suspended particle devices (SPD), a thin film laminate of rod-like particles suspended in a fluid is placed between two glass or plastic layers, or attached to one layer. When the power supply is switched on, the rod shaped suspended particle molecules align, light passes through and the SPD Smart Glass panel clears. When the power supply is switched off the rod shaped suspended particle molecules are randomly oriented blocking light and the glass panel looks dark (or opaque), blue or, in more recent developments, grey or black color. the SPD Smart Glass when becomes dark can blocking up to 99.4% of light. SPD Smart Glass protect from damaging UV when on or off.

So, SPD can be dimmed, and allow instant control of the amount of light and heat passing through. It consists of several layers as shown in (fig. 8,9):

- Two panels of glass or plastic
- Conductive material - used to coat the panes of glass
- Suspended particle devices - millions of these black particles are placed between the two panes of glass
- Liquid suspension or film - allows the particles to float freely between the glass
- Control device - automatic or manual.

Polymer Dispersed Liquid Crystal devices (PDLC)

In polymer dispersed liquid crystal devices (PDLC), liquid crystals are dissolved or dispersed into a liquid polymer followed by solidification or curing of the polymer. Typically, the liquid mix of polymer and liquid crystals is placed between two layers of glass or plastic that includes a thin layer of a transparent, conductive material followed by curing of the polymer, thereby forming the basic sandwich structure of the smart window (Elkadi H. 2006).

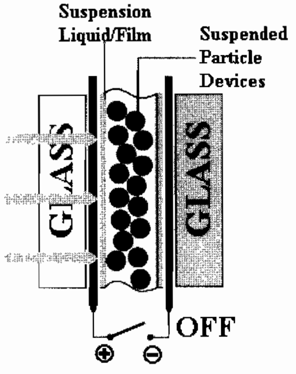

Figure (8): Shows When switched off, SPD window remains translucent.

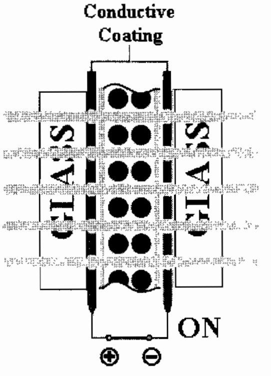

Figure (9): Shows When switched off, SPD window remains transparent.

Figure (10): When SPD Smart Glass off

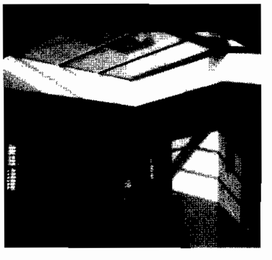

Figure (11): When SPD Smart Glass on

This structure is in effect a capacitor. Electrodes from a power supply are attached to the transparent electrodes. With no applied voltage, the liquid crystals are randomly arranged in the droplets, resulting in scattering of light as it passes through the smart window assembly. This results in the translucent, "milky white" appearance. When a voltage is applied to the electrodes, the electric field formed between the two transparent electrodes on the glass cause the liquid crystals to align, thereby allowing light to pass through the droplets with very little scattering, resulting in a transparent state (fig 12,13). The degree of transparency can be controlled by the applied voltage. This technology has been used in interior and exterior settings for privacy control (for example conference rooms, intensive-care areas, bathroom/shower doors) and as a temporary projection screen.

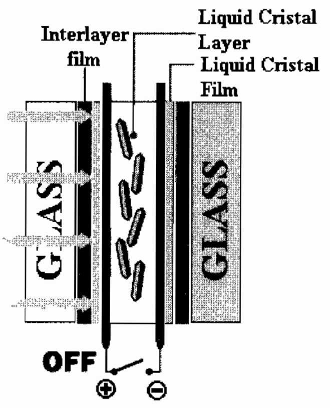

Figure (12): Shows when switched off, PDLCwindow remains translucent.

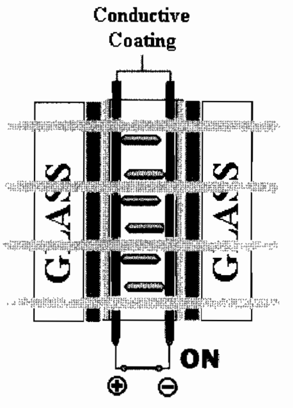

Figure (13): Shows When switched on, PDLC window remains transparent.

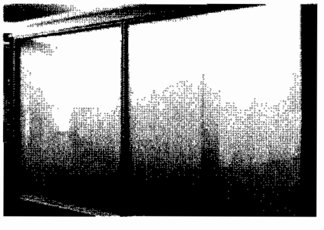

Figure (14): When PDLC Smart Glass off

Figure (15): When PDLC Smart Glass on

Also, (PDLC) glass can already be found in offices and homes around the globe. Because it can achieve a translucent setting, PDLC technology is great for homes and offices, you get privacy without sacrificing all light.

Table 1 shows a comparison between the three different kinds of switchable glass (EC,SPD,PDLC) in characteristics and behavior in architectural activities.

	EC	SPD	PDLC
When is transparent?	Switched OFF	Switched ON	Switched ON
Continuous states between opaque and transparent?	Yes	Yes	No

Requires power to maintain the state?	No	Yes	Yes
Shading Benefit	Yes	Yes	Nominal (diffuses light)
Switching Speed	Varies depending upon panel size; May take many minutes for large format Panels	Several seconds regardless of panel size	Milliseconds regardless of panel size
Light-control States	Typically 2 preset levels from dark to clear	Unlimited levels from very dark to clear	2 (translucent and transparent)
Light Transmission in dark/opaque	SHADING: Yes PRIVACY: Typically some view remains	SHADING: Yes PRIVACY: Yes	SHADING: Nominal PRIVACY: Yes
Energy Used to Operate	Very low	Very low	Very low

4.2 The benefits of smart glass

Active smart glass will play an increasingly important role in the world's drive toward sustainability. Requiring very low amounts of power to operate. Architects and designers can integrate smart glass into their projects in ways that offer unprecedented control over incoming light, glare and heat. In doing so, electrical energy consumption can be lowered, cooling loads reduced, environmental impact mitigated and occupant well-being increased. These outcomes can be achieved by the integration of smart glass into various day lighting strategies. Most fundamentally, smart glass transforms conventional windows into smart windows with expanded daylighting utility and value. For example, curtains, blinds and other treatments have traditionally been used to provide shading and glare reduction through incoming windows.

These solutions typically block one's view to the outside, an undesired outcome for many building occupants. Windows with smart glass allow users to control incoming light, glare and heat without the loss of view to the outside.

Generally there are a lot of benefits of using smart glass such as:

- Instant and precise control of light.
- Energy Savings on cooling & lighting costs.
- Eco friendly, reduce building carbon emissions.
- Exceptional optical qualities that reduce glare and eye strain.
- Elimination of the need for expensive window dressings like electronic louvers; blinds and solar shades used in architectural applications.
- High durability, solid-state technology with no moving parts to wear out or break.
- Infinite range of light transmission levels without blocking of view.
- Stable color characteristics for the life of the unit.
- Wide working temperature range from -20°c to +70°c – Ideal for exterior applications, ambient temperature control.
- Wide light transmission ranges.
- Hygienic low maintenance material.
- Reduced fading of carpets, furniture and protect valuable artwork.
- Reduces uncomfortable feeling when living or working in high-density buildings such as apartment blocks or office complexes.
- Protecting skin from damaging UV rays.
- Low working voltage.
- High contrast at any viewing angle and any illumination level.
- Long life – tested to in excess of 100,000 cycles.
- Aesthetically pleasing and cost competitive.

Table 2 shows the wide benefits of using smart glass in smart windows comparative with conventional windows:

Conventional Window with Static Tint and Interior Blind/Shade	**Smart Window**
Static window tint degrades view to outside during low/no-sun periods	View to the outside is optimized even during low/no-sun periods
Partial shading from interior blind obstructs view	Variable shading does not obstruct view
Space consumption is relatively high	Space consumption is relatively low
Shading/privacy requires manual effort to close blinds or activation of expensive motorized shade	Sensors adjust light conditions automatically; manual light-control is as simple as turning a dial
Occupants less likely to control/optimize light levels	Ease-of-use and integration with sensors optimizes light levels
Daylighting benefits are not optimized	Daylighting benefits are optimized

5 Test Model Study

A test model study was carried out at the united states by Lawrence Berkeley National Laboratory (LBNL), division of environmental energy technologies on the electrochromic glass windows capabilities of reducing energy consumption (Lee E.S., DiBartolomeo D. L. & Selkowitz S. E. 2000).

Incorporating Electrochromic glazings could reduce peak electric loads by 20 to 30% in many buildings and increase daylighting benefits. These technologies will provide maximum flexibility in managing energy consumption and will move the building community toward the goal of producing advanced buildings with minimal impact on the energy resources.

Electrochromic windows have been installed in two adjacent office test rooms, enabling researchers to conduct full-scale monitored tests (Figures 16 and 17). Full-scale tests bring laboratory devices one step closer to commercialization by solving key design problems in a short test-evaluate-test iterative cycle of development within a realistic building environment. At this time, large-area windows (90x200 cm) are technically viable.

5.1 Method

Large-area electrochromic windows were installed in two adjacent test rooms in an office building, test objectives included developing control systems, monitoring energy use, and evaluating visual comfort in both cases.

Each test room was 3.71 m wide by 4.57 m deep by 2.68 m high and furnished with nearly identical building materials, furniture, and mechanical systems to imitate a commercial office environment. The conventional and the Electrochromic windows in each room were simultaneously exposed to approximately the same interior and exterior environment so that measurements between the two rooms could be compared. A laminated electrochromic glazing was combined with a low-emittance (low-E) glazing to form a double-pane window with a visible transmittance (Tv) range of 0.14 to 0.51. Each electrochromic double-pane window was then mounted on the interior side of the building's existing monolithic green-tinted glazing (Tv=0.75). The overall composite Tv range was therefore 0.11 to 0.38. Electrochromic windows were placed in an array of five upper and five lower windows to cover the full area of the window opening (3.71 m wide by 2.29 m high) as shown in Figure 6 and all were switched with a voltage between 0-3 V.

The system was automated, switched electrochromic windows integrated with the dimmable fluorescent lighting system to maintain an interior work plane illuminance of 510 lux throughout the day. Daily lighting & horizontal illuminance was measured at a work plane height of 0.76 m in a two by five array of Li-Cor sensors. Window luminance data were collected with a shielded sensor placed on the rear wall of the test room facing the window.

Figure (16) Before direct sunlight enters the windows, The electrochromic windows are in the clear state.

Figure (17) After direct sunlight enters the window, the electrochromic glazing switches to its fully colored state

5.2 Results

The electrochromic window system tested had excellent optical clarity, no coating aberrations (holes, dark spots, etc.); uniform density of color across the entire surface during and after switching, smooth, gradual transitions when switched; and excellent synchronization (or color-matching) between a group of windows during and after switching. The windows had a very slight yellow tint when fully bleached and a deep prussian to ultramarine blue when fully colored.

The glazings were not reflective. To all outward appearances, the Electrochromic windows looked exactly like conventional tinted windows with the exception that one can change their coloration.

Electrochromic glazings save energy by reducing cooling loads and reducing electric lighting energy consumption when dimmable lighting systems are used. In tests conducted during the winter, the focus was on the lighting energy impacts. Ceiling mounted photo sensor controls were used to modulate the glass transmittance and maintain a light level of 510 lux at the work surface. When insufficient daylight was available, the electric lights provided the additional required illuminance. When comparing the electrochromic glazings to a static dark glass (Tv=11%) on sunny and overcast days, the daily lighting energy consumption for the room with the electrochromic windows was on the order of 6 to 24% lower. Whenever direct sunlight enters the room, the electrochromic window switches to its darkest state (11%), so there are no savings relative to the static glazing. But much of the time in the afternoon, there is no direct sunlight on these facades, and under most overcast conditions the Electrochromic window switches to a clearer state, allowing the lights to be dimmed, saving energy (Figure 17).

However, when the electrochromic glass is compared to a higher transmittance glass (Tv=38%), the lighting energy use is actually 0 to 13% greater. This is because the static glazing always transmits as much light as or more light than the electrochromic, which will often be switched to control direct sunlight, thus requiring some added electric light. Overall, however, the high-transmittance static glass is likely to have higher cooling loads and result in more glare problems. And in an occupied space, people would likely have added blinds or shades to control glare, further reducing the apparent advantage of the clearer static glazing (Lee E.S. 2006).

5.2.1 Future directions for Electrochromic glass

Two strategies can improve lighting energy savings with electrochromic glazings: increase the upper Tv limit and decrease the lower Tv limit for glare control. For this test, the upper Tv limit could have been increased if the existing building glazing had been removed. This work also suggests that it may be advantageous for electrochromic devices to have a larger contrast ratio and higher transmission in the bleached state; for example, a device that can switch between Tv=0.06-0.85 will have greater daylight efficacy and control over intense sunlight than the device tested. Additional field tests will be conducted to better understand electrochromic glazing properties, the relationships between these properties and lighting savings, cooling savings, and occupant satisfaction and methods to integrate dynamic control of the window system with whole building energy management systems.

6 Conclusion

The twenty-first century has ushered in a period of pressing threats to the environment, rising energy costs, and a firming resolve that sustainable architectural design can yield dramatic gains in long-term resource preservation and overall quality of life. Supporting all of this is the growing portfolio of clean technology products and processes that not only advance sustainable ideals but do so profitably.

Smart glazing technology is poised to propel sustainability to new levels. Electrochromic windows can deliver significant energy savings, visual comfort, and greater access to view managing direct sunlight and glare.

Smart glass can help the architectural community achieve its sustainability goals by reducing electricity consumption used to power interior lighting, lowering cooling costs and improving the health and well being of occupants. As adoption of smart glass accelerates and prices decline, it is likely the category will move from one being used by early adopters to one being sought after by the mainstream.

Smart glass manufacturers should develop an accurate intermediate-state controller and work toward faster switching speeds, less color in the tinted state, lower minimum transmittance, and reduced manufacturing costs in order to use it widely specially in hot and sunny areas.

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