RESEARCH ON SMART WINDOW TECHNOLOGY

Building lighting loads in buildings account for a large percentage of electricity consumption and heat generation. Being able to utilize natural daylight to illuminate interior spaces would reduce electric loads from fixtures and ballasts that would normally provide lighting. The problem with too much lighting is the amount of fenestration on a buildings envelope. The larger the amount of fenestration, the more sunlight will enter the building, but heat is also incorporated with daylight. Large fenestrations are often associated with heating losses in the winter through the windows to the outside environment. In today's advanced technological field, many new products and ideas are making their way into testing facilities and buildings. Finding ways to bring sunlight into the building without the large thermal loads and still trying to provide enough light to reduce the energy used by artificial lighting is an ongoing task with many possibilities.

Smart windows are being applied to buildings to study the controllability of natural light, artificial light, thermal loads and occupant comfort (visually and thermally). There are a variety of smart windows that all perform the basic approach of privacy and comfort, but have very differing technologies associated with them. Photochromatic windows are controlled by sunlight and become cloudy under a bright sky. Thermochromatic windows are controlled by temperature, which will change the color of the material in the window. Electrochromic windows are controlled by an applied voltage, which can darken and lighten the window by reversing polarity.

Some other types of technologies used in controlling window appearance are polymer dispersed liquid crystals, suspended particle devices and reflective hydrides. Polymer dispersed liquid crystals have two stages, opaque and clear. It is mainly used for privacy than anything else. PDLC's contain liquid crystal droplets in a polymer mixture which is contained between two transparent conducting materials. The liquid crystals are randomly scattered throughout the polymer mixture, creating an opaque state, until a voltage is applied across the conducting materials, the crystals align themselves parallel to the electric field and the window becomes clear. While in the opaque state, 99% of the UV rays are prevented from entering the building. The windows consume approximately 5 W/m^2. These windows come in a variety of colors and can be applied to mirrors.

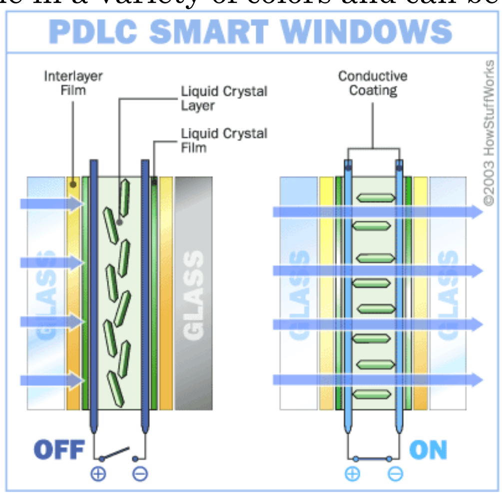

Figure 6. PDLC windows, courtesy of HowStuffWorks

Suspended particle devices are light absorbing microscopic particles. When placed in a liquid suspension film, then placed between two pieces of transparent conductive objects, the particles randomly align themselves and block light from entering the window. When a voltage is applied across the two conductive materials, the particles align themselves parallel with the electric field and the light is able to pass through the window. The amount of power needed to convert these windows is so small, that a residential house with these types of windows would use as much power as a small lamp/light for the day. Once the power is removed the particles realign themselves back to their original state. Electrified variable tint SPD windows have a fairly quick response rate as well as a large switchable durability. These windows can control solar light transmittance between 0.1% and 70%. The average power consumption is less than 5W/ft^2.

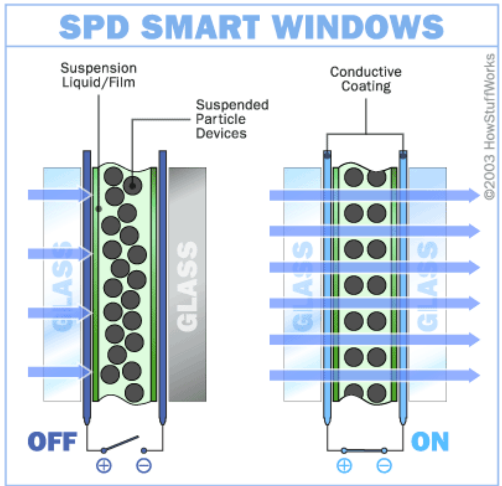

Figure 7. SPD window, courtesy of HowStuffWorks

Reflective hydrides are films made of nickel-magnesium alloy, which reflect light. They are powered either by low voltage or by the injection of hydrogen and oxygen gasses (gas-chromatic technology) which transform the window to a clear state. The difference in these windows is that they reflect light rather than absorb it. Reflecting light is good, but not at neighboring buildings which pick up the thermal load. Obviously, these windows would be used in a non-urban environment.

The type of window proposed to be installed in the Heritage Center is electrochromic glass manufactured by SAGE Electrochromics, Inc. A ceramic ion conductor is sandwiched between a counter electrode and an electrochromic electrode. These layers are then sandwiched between two transparent conductors which are located on the inside of the glass layers. Multiple layers of ceramic thin films are applied to the glass where it is fired on to ensure a strong, durable window. These windows consume low DC voltage to transfer ions from one layer to another, which in turn, tints the window. Electronic dimmable ballasts can be used to transform AC to DC for the windows. Unlike SPD's SageGlass cannot become totally opaque, so visibility through the window is never obstructed. Visible light ranges from 4% to 70% through the window at its darkest and lightest stages, respectively. In its clearest stage SageGlass blocks 95% of the UV radiation (99% in its darkest stage), which is helpful in preventing the interior components (furniture, paintings, tapestries, etc.) of the building from fading. The windows can be controlled as a functional parameter; a function of direct/total solar radiation, tonnage, previous space loads or indoor lighting levels. The windows have a "memory" associated with them. Unlike the SPD's, these windows will maintain tinted once the power source is taken away. Various cases ranged from 12-48 hours until the window went back to its original state.

Electrochromic windows have drawbacks as well. During the cold winter months, the windows require a longer time to switch than in the warmer, summer months. Thermal shock is the factor that affects the timing delay. The window is not at the same temperature everywhere, and if switching occurs too fast, the window could crack or shatter. The larger the window, the longer the time it takes to fully change coloration. Fading of the window color occurs over time as the window appears more "yellowish" in its clear state (this is due to the hydrated polymers). Even though tinting capabilities seem ideal in the hot summer months, the darkening of the windows increases the absorptive properties. The window temperatures can reach temperatures as high 122 degrees F, which will, in turn, radiate heat into the cooler building. Cost is the biggest drawback of the windows. Currently the windows are, on average, \$1,000.00/ft^2, which corresponds to the fact that the technology associated with these windows is not well known. If production and demand significantly increase or if utility companies offer rebates or if building codes and regulations require such windows in a building, prices will decrease. An acceptable cost of the windows would be around \$100.00/ft^2, but even that price is hard to compete with \$20.00/ft^2 for a typical quality window.

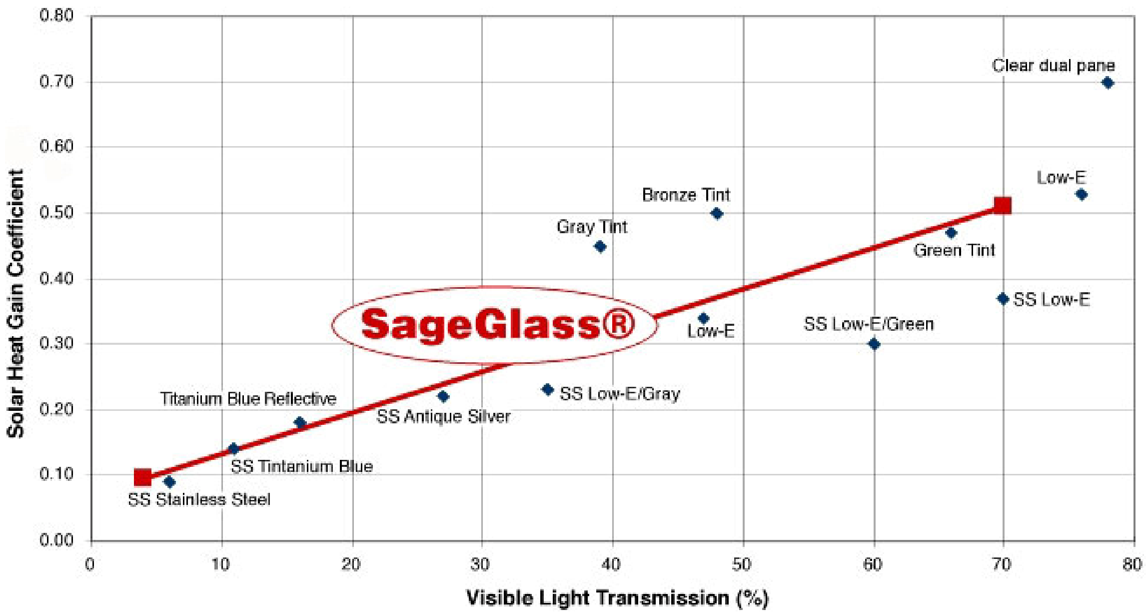

Figure 8. SHGC vs. VT of SageGlass, courtesy of SAGE Electrochromics, Inc.

SageGlass properties	
U-factor (Center of Glass)	0.33
Air Gap	½" Argon
Coating Properties	Low-e

Table 4. SageGlass properties obtained from SAGE Electrochromics, Inc.

Several studies and experiments were studied using electrochromatic windows in a typical office space. The study integrated the electrochromatic window controls with the fluorescent lighting to maintain a set illuminance in the room, monitored by light sensors.

The electrochromatic windows were actually placed inside of the existing windows in the office, so a thermal analysis could not be conducted. The windows experienced an exponential time change; they reached 50% change in 25% of the total time to change 100%. Because of the exponential character of the window, the windows were not able to keep up with the constantly changing outdoor conditions. The windows averaged 9-26 minutes in changing times, while the outdoor conditions could change in seconds. No control was possible to block direct sun. The ratio of light on the surfaces in the room stayed the same, so the problems with glare on computer screens were not solved (image washout and veiling reflections). Energy savings through lighting were obtained, but as mentioned above, problems were realized. It was determined that electrochromic windows cannot control direct sun and daylighting simultaneously. Other analyses to consider are energy and peak demand costs, effects on mechanical equipment (heating and cooling), environmental effects, human comfort and operation costs.

Aesthetics is another area where electrochromics might not be compatible. Suppose a large office building has electrochromic windows, each individually controlled. At times, the façade of the building would have different patterns of shaded glass. The most feasible arrangement for any space would be to have several smaller, individually controlled pieces of glass in one window frame. This would allow the windows to darken in the path of the sun and allow indirect light in throughout the rest of the window.