ScottMadden
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Smart Windows Technologies

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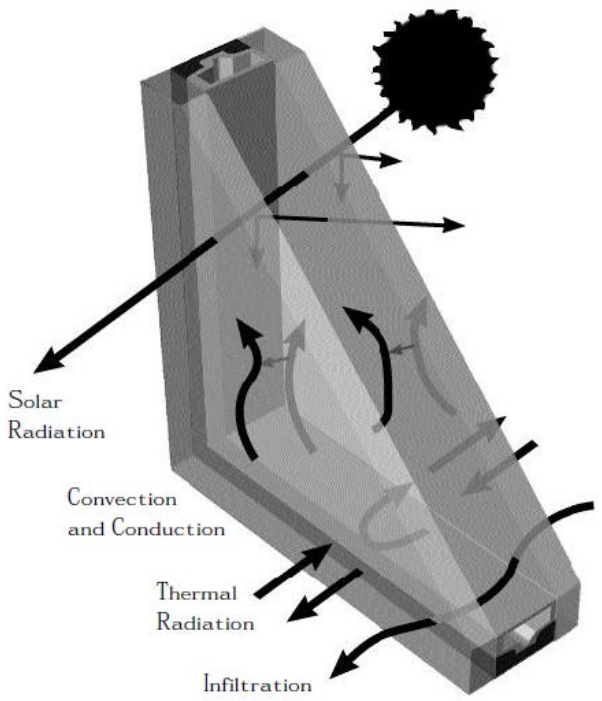
Smart Window Overview

Background

- According to the U.S. Green Building Council, buildings account for nearly 40% of all energy consumed in the United States
  - Poorly insulated windows can account for 10%–30% of a building's heat loss in winter months, while summer light penetration increases the amount of energy required to maintain comfortable living or work environments
- The majority of buildings utilize double-, triple- or quadruple-paned glass which incorporate low-emittance (low-e) coatings and gas fills while window treatments, like curtains, blinds ,or shades may be used to limit the amount of light transmitted through windows
- A new generation of windows, also known as "Smart Windows," "Smart Glass," or "Switchable Glazing" incorporates technologies that control the amount of light, glare, and heat transmitted through the glass while providing a high level of insulation
  - When used effectively, Smart Windows can reduce peak demand by impacting heating, cooling, and lighting consumption
- Smart Window technologies include:
  - Photocromics or photochromatics
  - Liquid Crystals
  - Suspended Particle Displays
  - Electrochromics
- Some Smart Window technologies are commercially available while others are still under development

Current Window Technology



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Photocromics and Photochromatics

Definition

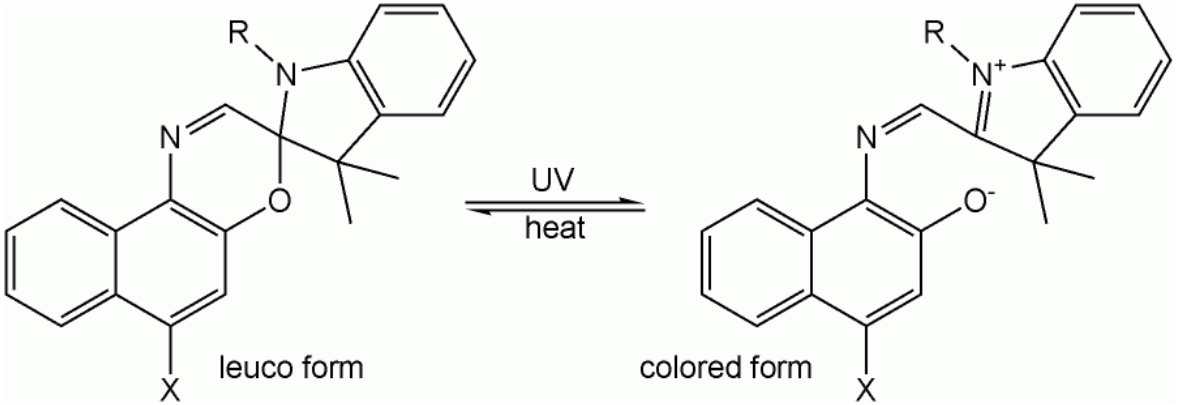
- Photochromism is the reversible transformation of a chemical species between two forms by the absorption of electromagnetic radiation, where the two forms have different absorption spectra
- Photochromism can occur in both organic and inorganic compounds
- The terms photocromic and photochromatic are used interchangeably

Photocromic or Photochromatic Windows

- Photocromic window applications are generally small in scale. Larger applications generally involve the use of films applied to the top of a glass or plastic surface (tinting)
- Photocromics have applications outside of window tinting that range from functional to aesthetic

Other Commercial Applications

- Color-changing sunglass lenses
- Supramolecular chemistry
- Data storage
- Novelty Items



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Photochromics and Photochromatics (Cont'd)

Technological Challenges

- Photochromic applications work well to reduce glare from the sun, but they do not control heat gain
- Photochromics are not as versatile as other Smart Window technologies because they cannot be manually controlled
  - Example: a photochromic window may darken on a cold sunny day when more solar heat is desired

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Liquid Crystal and Polymer Liquid Crystal

Definition

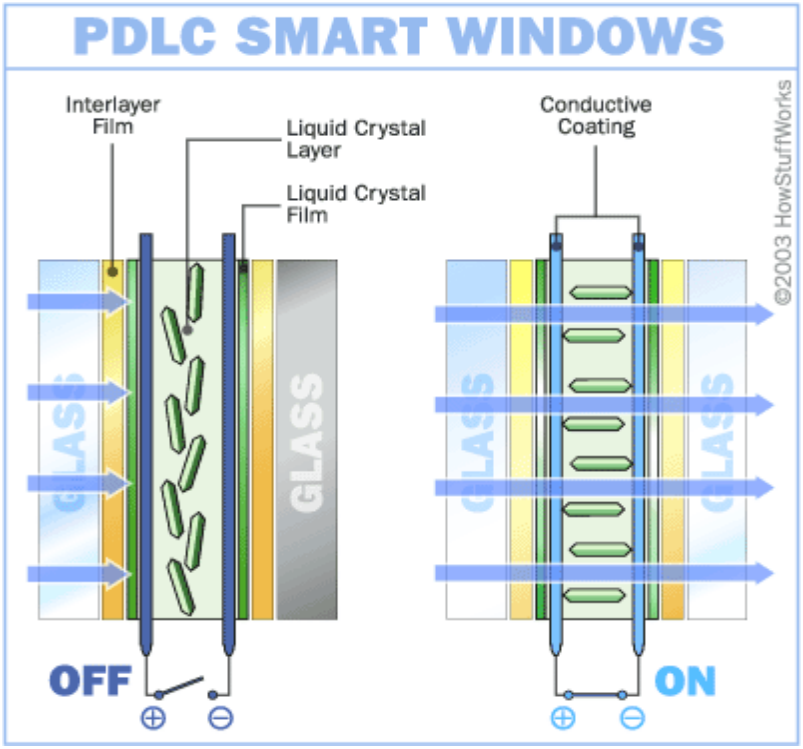
- Liquid crystals are substances that exhibit a phase of matter that has properties between those of a conventional liquid and those of a solid crystal. Electricity is used to change the shape of the liquid crystals to allow light to pass through
- While liquid crystal displays (LCD's) are common—used in calculators, digital clocks, etc., polymer liquid crystal displays (PDLCs) are a relatively new method for combining polymers with liquid crystals in various glazing applications
- With LCD/PDLC technology, the glass is either clear or translucent. There are no intermediate settings

Liquid Crystal Windows

- Primary function is to provide privacy and reduce glare (as a substitute for conventional shading devices)

Commercial Applications

- Privacy glass for:
  - Security applications
  - Office partitions
  - Displays (commercial)
  - Skylights
  - Bedroom/bathroom applications



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Liquid Crystal and Polymer Liquid Crystal (Cont'd)

Representative List of Manufacturers

- Polytronix, Inc.
- Prodisplay
- Switchlite
- Smart Glass International (UK)
- iGlass (Australia)
- AGP (Australia)
- Many others for various applications

Technological Challenges

- Liquid crystal windows do not provide significant energy savings since the window lets in nearly the same amount of light and solar heat whether it is on or off
- A constant electrical charge is required to maintain a transparent state
- Liquid crystal glazing currently adds about $\$90/ft^2$ to the glazing

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Suspended Particle Display (SPD)

Definition

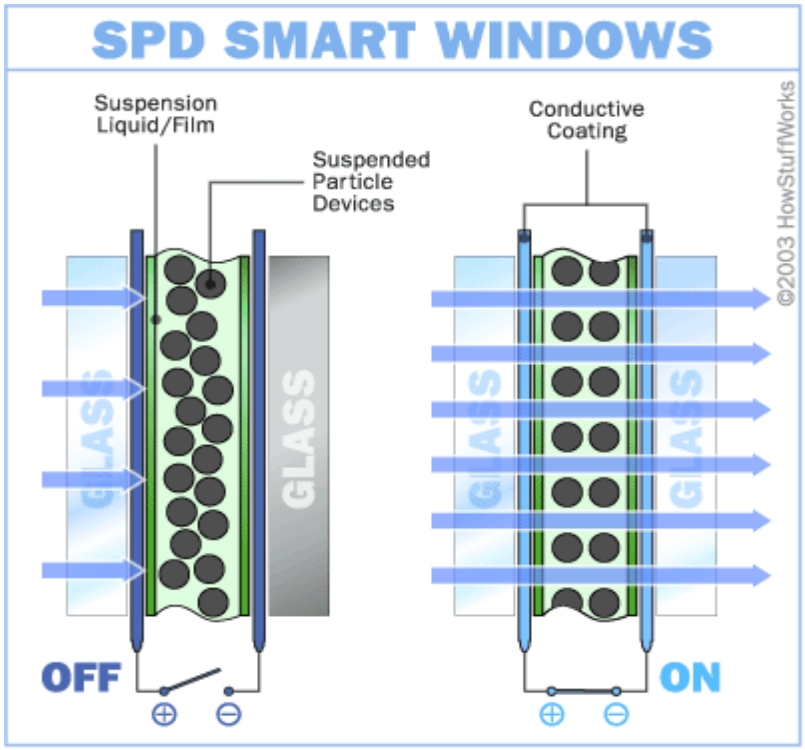
- SPDs are microscopic molecular particles which are suspended in a liquid solution and then placed on a conductive sheet or film. When no electrical voltage is present, the particles absorb light and block it from passing through the film. When an electrical voltage is applied, the particles align so that light can pass through. By regulating the voltage with a simple switch or other control device, users instantly regulate the amount of light, glare, and heat coming through products such as windows
- SPD products block more than 99% of UV light

Commercial Applications

- Architectural – windows, doors, skylights, and partitions
- Aerospace – windows, doors, and partitions
- Automotive – sunroofs, side and rear windows, visors, mirrors
- Appliances – windows and doors on refrigerators, ovens, microwaves
- Marine – windows, doors, hatches, and partitions
- Eyewear – prescription and non-prescription glasses, goggles, and helmet visors
- Displays – advertising signage and displays, computer screens, cell phones, and light filters

Representative List of Manufacturers

- Innovative Glass Corporation
- Research Frontiers
- Smart Glass International (UK)



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Electrochromics

Definition

- Electrochromics can change the light transmittance, transparency or shading of windows in response to a stimulus such as sunlight, temperature, or an electrical control
  - Electrical control systems include wall switches, timers, motion sensors, lighting control and thermostats
  - Electrochromic (EC) glazing has "memory" and does not need constant voltage to maintain the tinting
  - EC film can be tuned to block certain wavelengths, such as infrared (heat) energy
  - The second generation of electrochromics utilizes reflective hydrides which are made out of nickel-magnesium alloy. This allows sunlight to be reflected in tinted state instead of absorbed—this is expected to result in a more efficient product

EC Windows

- The race for a profitable and reliable EC production process has been pursued for more than 20 years
  - The first EC products became commercially available in 2006
- A 1999–2000 study of early-generation EC windows performed by the Lawrence Berkeley National Laboratory found:
  - When comparing the EC glazings to a static dark glass (Tv=11%), the daily lighting energy consumption for the room with the EC windows was on the order of 6%–24% lower than the static dark glass windows
- A 2006 study of EC windows performed by the Lawrence Berkeley National Laboratory found:
  - EC windows were 44% ±11% more efficient than windows that did not utilize window treatments
  - Switching from “bleached” (clear) to full color (tinted) took six to seven minutes when temperatures >50ºF while switching could take 40–85 minutes to reach full coloration when exposed to colder temperatures

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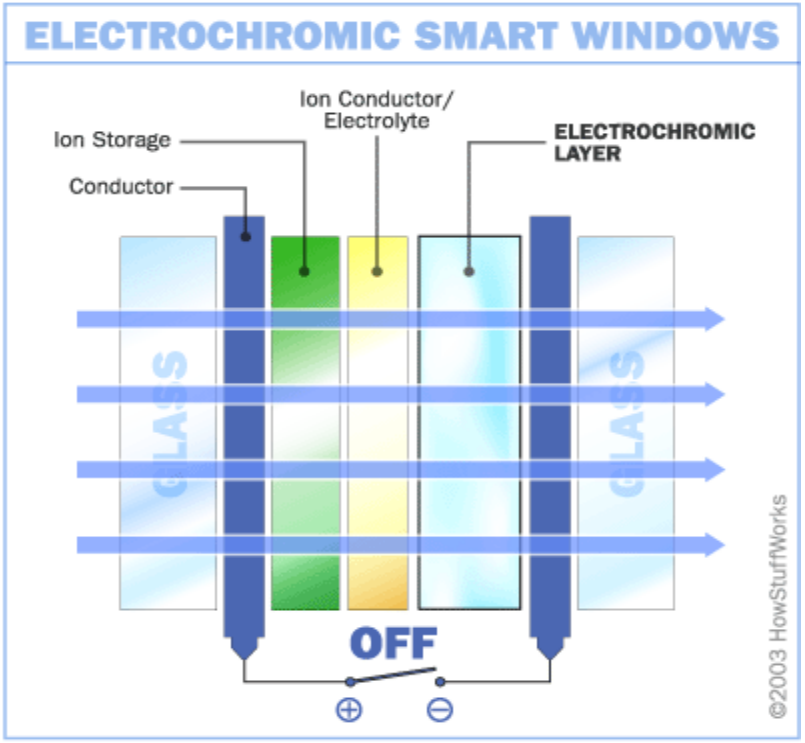
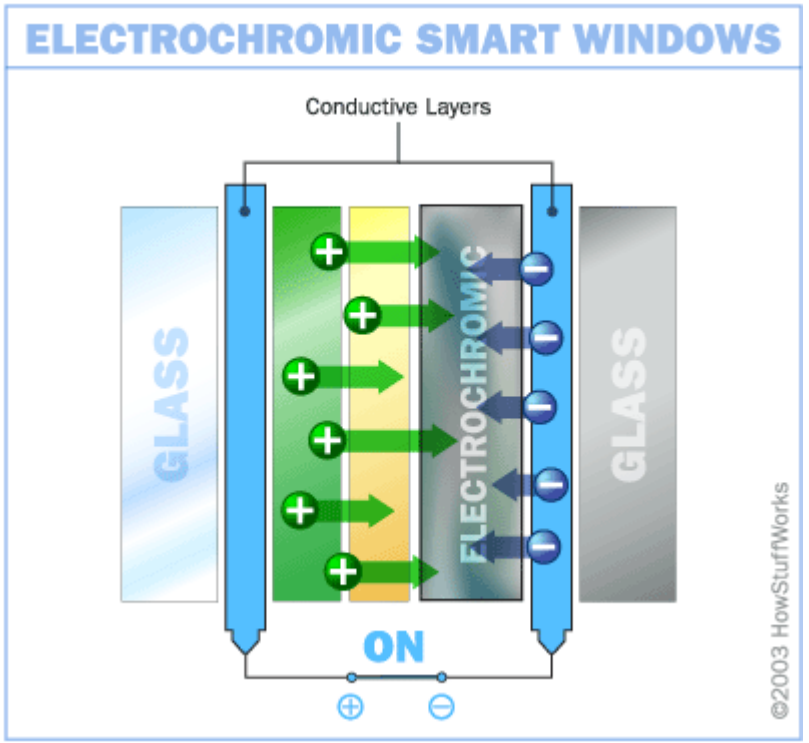
Electrochromics (Cont'd)

- EC windows consist of up to seven layers of materials. An electric charge drives the ions from the ion storage layer through the ion conducting layer and into the EC layer, resulting in a reduction in solar penetration. Reversing the charge returns the window to a transparent state



When switched off, an EC window remains transparent



When switched on, a low volt of electricity makes the EC window translucent

Electrochromics (Cont'd)

Commercial Applications

- Architectural – windows, doors, skylights and partitions
- Automotive – EC rear-view mirrors (sales had reached about 10million units in 2007)
- Aerospace – The new Boeing 787 Dreamliner features EC windows, replacing pull down window shades
- Space Exploration – NASA is looking into the use of EC technologies to manage the thermal environment of space vehicles

Industry Claims

- According to Sage Electrochromics, you can power and control 1,500 ft^2 of EC glass (approximately 100 windows) for about the same amount of money that it takes to power a single 60–watt light bulb
- Photovoltaic cells incorporated into electrochomic windows could be used to darken the window in sunlight without the use of an external electrical source
- The National Renewable Energy Laboratory (NREL) claims that EC windows have the potential of reducing the annual U.S. energy consumption by several quadrillion (10^{15}) Btus, or quads
- In 2006, The Lawrence Berkeley National Laboratory concluded that occupants "judged the EC window system as significantly more desirable than the reference window due to perceived reductions in glare, reflections on the computer monitor, and window luminance"

Electrochromics (Cont'd)

Industry Payback Estimates:

- EC windows are expected to be cost competitive within the next decade
- Analysis done in the late 1990s estimated:
  - "Even at this early stage of EC window development, savings of $0.21 per square foot in areas of the country that have cooling-intensive building loads have been calculated, based on $0.08/kWh electricity costs. Thus, a medium-sized office building (100,000 square feet), with windows covering 60 % of the outside surface, could see operating savings on the order of $21,000 per year if smart windows are used. Over a 25-year life, these savings would have a present value of $365,000*. Cost analysis that includes direct energy costs, initial chiller investments, utility demand-side management rebates, and lighting savings indicate that smart windows (at an added first cost of $161/m2) could pay for themselves in as little as four years"
  - $20 billion is the estimated value of the energy lost through the windows of buildings in the United States each year. This represents more than 5% of total U.S. annual energy use
  - Globally, a phased-in total transition to Smart Windows systems in office buildings could translate into energy savings on the order of $11.5 billion to $22.5 billion per year
- U.S. DOE estimates that electronically tintable window systems are capable of providing up to:
  - 40% savings on energy bills
  - 20% savings on operating costs
  - 24% reduction in peak demand
  - 25% decrease in the size of HVAC systems
- Sage Electrochromics predicts cost reductions of 78%–100% over the next ten years to a cost of $6–$8/ft^2. In addition to cost reductions, Sage expects that product performance and features will advance

** Present value calculation is based on a 3% real [net of inflation] discount rate, and assuming stable energy costs [also net of inflation]*

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EC (Cont'd)

Representative List of Manufacturers

- Sage Electrochromics (in conjunction with 3M)
  - Marvin Windows and Doors (distributor)
  - VELUX skylights dealers (distributor))
  - Weather-Tek Design Center (distributor)
- Gentex Corporation
- PPG Aerospace
- Many others

Technological Challenges

- EC windows are not currently "plug and play," which means they may require education and coordination of electrical and carpentry trades to install
- Challenges in fabricating EC windows lie in achieving low costs, high durability, and practical sizes
- In 2000, large-area EC windows (90 x 200 cm) were technically viable but could only be produced in small quantities at a cost of ~$1,000/$m^2$
  - Even now, the cost of EC windows can be from two to three times that of a standard window. These costs are expected to decrease significantly when manufacturing techniques have improved and quantities have increased
- The 2006 Berkeley Study recommended that "EC manufacturers 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"
- Work is needed to develop integrated window-lighting control algorithms that accommodate different visual tasks building occupancies and climate/HVAC conditions

Window Market Size

Prior to the current recession, a number of analysts predicted that the market for Smart Glass technologies was expected to grow significantly.

Window Market Size

- The value of Smart Glass demand in the United States is expected to reach $1.34 billion by 2015, an increase of 250% from the 2005 market size of $38.3 million
- Globally, flat glass demand in 2004 was 43.1 billion ft^2 (4.0 billion m^2), and was expected to grow more than 20% to 52.0 billion ft^2 (4.8 bil m^2) by 2008
- The design community has very high expectations for the use of Smart Glass. A 2004 study of U.S. architects by Research Frontiers finds that architects expect 13.5% of all windows, doors and skylights installed or retrofitted in 2009 will use Smart Glass
- According to the Townsend Research Group, U.S. window manufacturers expect strong end-user interest in Smart Glass for both residential and commercial architectural applications. There also is a significant market for the retrofitting of existing glass products like windows and sunroofs
- In 2006, the Freedonia Group stated that a growing number of original equipment manufacturers in the transportation markets are using greater amounts of glass or polycarbonate glazings. The Freedonia Group estimated that worldwide demand for automotive sunroofs was expected to grow at more than 10% per year through 2010
- Growth can be partially attributed to the broad movement toward sustainable building design
  - See next slide for detail

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Annual Space-Conditioning Energy Consumption

Windows account for as much as 30% of building heating and cooling loads. The high-efficiency factors found on Smart Windows, especially EC windows, have the potential to minimize the amount of energy required to condition residential and commercial buildings.

Annual Space-Conditioning Energy Consumption of Current U.S. Window Stock

	Residential		Commercial	
	Quads/Yr	% of Total Building Energy	Quads/Yr	% of Total
Heating	6.90	19%	2.45	35%
Cooling	2.41	39%	1.90	28%
Total	9.31	24%	4.35	32%

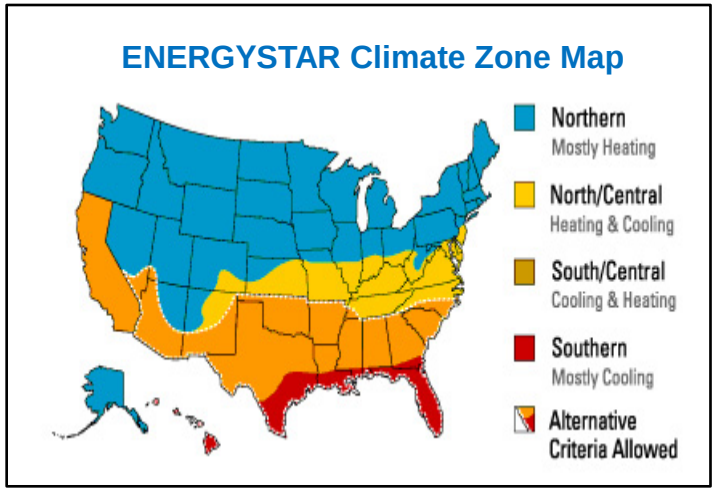
Notes:

1) *1 Quad = a unit of energy equal to 10^{15} BTU or 2.93 x 10^{11} kWh*
2) *United States consumed about 100 quads of energy in 2005*

Incentives and Rebates – Federal

Federal Incentives

- The Emergency Economic Stabilization Act of 2008 (P.L. 110-343) included, extended, and/or amended many tax incentives originally introduced in the Energy Policy Act of 2005 (EPACT)
- Consumers
  - The Energy Policy Act of 2005 allowed consumers to receive a federal tax credit for energy efficient improvements made on their homes in in 2006, 2007, and 2009. Energy efficient improvements made on homes in 2008 were not included
    - A tax credit worth 10% of cost, up to a limit of $200 per window and $500 per home is available. Windows and skylights must comply with requirements of the 2001 or 2004 supplements of the International Energy Conservation Code (IECC) or ENERGY STAR. Installation costs cannot be included in the cost of the window
    - All ENERGY STAR qualified windows and skylights that are installed in the taxpayer's primary residence and are qualified in the appropriate (corresponding) ENERGY STAR climate zone are eligible to receive a tax credit
- Businesses
  - There are a number of incentives available to businesses who address overall energy efficiency. Examples include:
  - Builders and Manufacturers Incentives
    - A credit of $2,000 is available to home builders who build homes (including both site-built and manufactured homes) projected to save at least 50% of the heating and cooling energy of a comparable home that meets the standards of the 2003 International Energy Conservation Code, including supplements. A $1,000 credit is available to manufactured home producers for models that save 30% or that qualify for the federal Energy Star



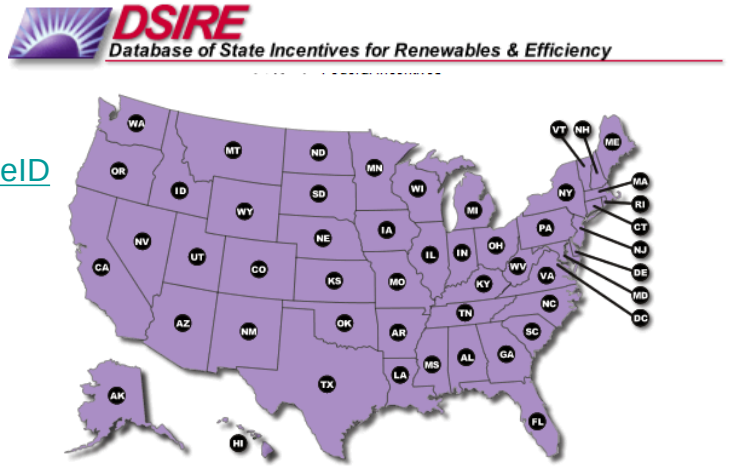
Incentives and Rebates – Federal (Cont'd)

- Businesses (cont'd)
  - Energy Efficient Commercial Buildings Tax Deduction
    - A tax deduction of up to $1.80 per square foot is available to owners or tenants (or designers, in the case of government-owned buildings) of new or existing commercial buildings that are constructed or reconstructed to save at least 50% of the heating, cooling, ventilation, water heating, and interior lighting energy cost of a building that meets ASHRAE Standard 90.1-2001
    - Only buildings covered by the scope of ASHRAE Standard 90.1-2001 are eligible. Partial deductions of $0.60 per square foot can be taken for improvements to one of three building systems—the building envelope, lighting, or heating and cooling system—that reduces total heating, cooling, ventilation, water heating, and interior lighting energy use by 16 2/3% (16 2/3% is the 50% goal for the three systems, spread equally over the three systems)
    - Expiration Date: 12/31/2013
  - Green Building (Extension & Modification of Qualified Green Building & Sustainable Design Project Bond)
    - The bill extends the authority to issue qualified green building and sustainable design project bonds through the October 1, 2012 by amending Section 142(l)
    - Smart Window technologies count toward Leadership in Energy and Environment Design (LEED) certification
      - Smart Windows can get LEED points for keeping heat out, or in as well as offering daylight and views
    - Qualified green building and sustainable design project bonds are not subject to the State bond volume limitations. The Secretary of the Treasury may allocate, in the aggregate, no more than $2 billion of bonds nationally to qualified green building and sustainable design projects

Incentives and Rebates – State

State Incentives

- States provide a number of incentives to homeowners and businesses for the installation of windows. Incentives available include:
  - Tax credits
  - Rebates
  - Loans
- Nationwide ,there are currently more than 200 energy incentive programs available to homeowners and business-owners to install energy-efficient windows
- Incentive programs are administered by:
  - State and local governments – through specific departments (i.e., energy, economic development, etc.) or through collaboratives created to manage the incentive programs
  - Utilities – with the goal of reducing peak load demand or mandated by regulatory agencies to include energy efficiency incentives
- For a comprehensive list of window efficiency incentives (sorted by state), go to: http://www.dsireusa.org/searchby/searchtechnology.cfm?&CurrentPageID=2&EE=1&RE=0



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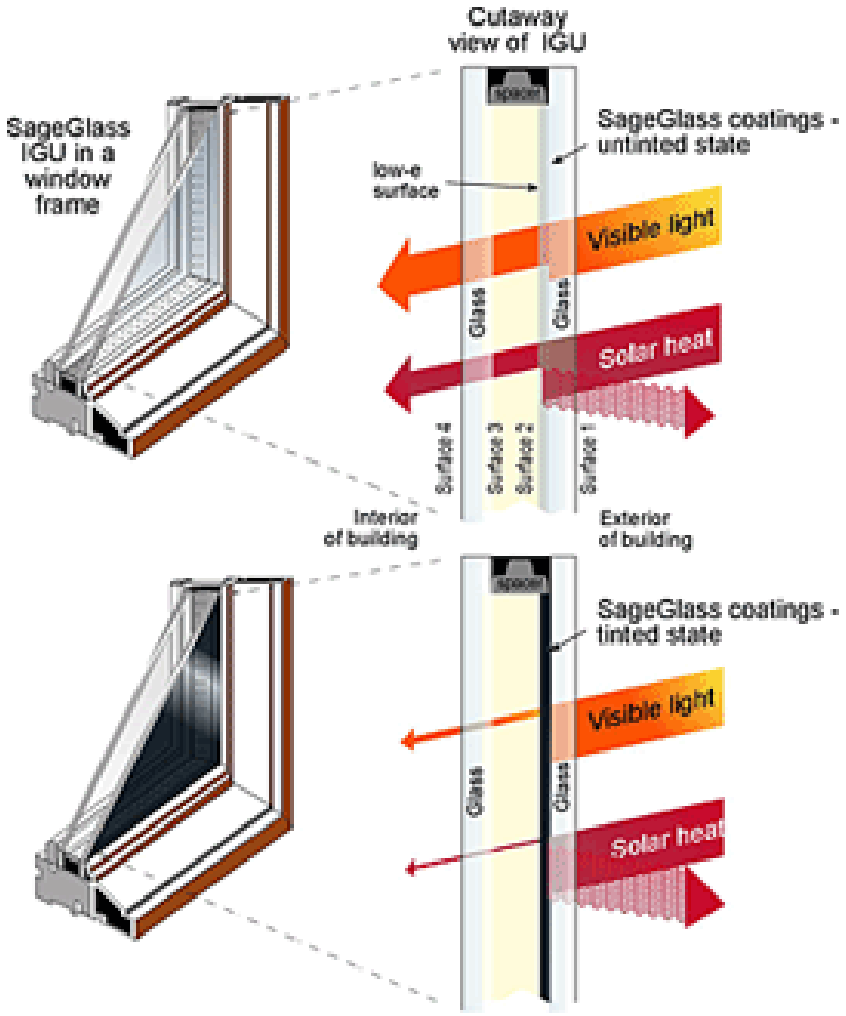
Comparison of Window Technologies

There are a number of window technologies available to consumers for a variety of applications. EC and SPD technologies are the best option for providing comfort, aesthetics, and energy efficiency.

Technology	Applications	When is it transparent?	Are there continuous states between transparent and opaque?	Does it require power to maintain the state?
Photocromics or Photocromatics	◆ Color-changing sunglass lenses ◆ Supramolecular chemistry ◆ Data storage ◆ Novelty Items	Absence of a light source	Yes	Yes, a light source
Liquid Crystals or Polymer Liquid Crystal	Privacy Glass	Switched On	No	Yes
Suspended Particle Displays	◆ Architectural ◆ Aerospace ◆ Automotive ◆ Appliances Marine ◆ Eyewear ◆ Displays	Switched On	Yes	Yes
Electrochromics	◆ Architectural ◆ Automotive ◆ Aerospace ◆ Space Exploration	Switched Off	Yes	No

Sage Electrochromics – EC Window Technology

A cross-section of the SAGE EC window



NFRC – Dynamic Glazing Label

In 2006, the National Fenestrations Rating Council (NFRC) created a special label for dynamic glazings. This should help consumers make informed purchasing decisions.

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Appendix-Window Comparison Switchable Glass: A possible medium for Evolvable Hardware, Mihai Oltean

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For more information on Smart Windows technologies, please contact us.

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