General Services Administration
Public Buildings Service

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ELECTROCHROMIC AND THERMOCHROMIC WINDOWS

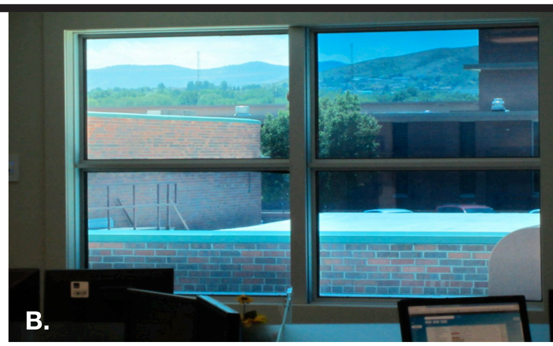
Chromogenic Windows Offer a Dynamic Approach to Energy Efficiency

The U.S. Department of Energy estimates that 30% of the energy used to heat and cool all buildings in the U.S.[1] is lost through inefficient windows at a cost of $42 billion per year.[2] Chromogenic windows dynamically transition from clear to dark in response to outdoor temperature and solar radiation, or to a signal from a switch or building automation system. These windows have the capacity to reduce HVAC and lighting energy use by controlling heat transfer and daylight transmittance in real time. Two types of chromogenic windows are now becoming commercially available: (1) thermochromic (TC), which uses adhesive coating to adjust tinting passively with window surface temperature; and (2) electrochromic (EC), which uses operable switches or automated building control systems to actively tint the window via electric current.

In 2011, GSA's GPG program deployed a pilot assessment of these windows in a Federal office building in Denver, Colorado, to evaluate product performance and user acceptance of this emerging technology. The still-developing nature of this technology prevents GSA from endorsing an overarching deployment strategy for chromogenic windows at this time; manufacturers have since made modifications to enhance product performance, and high-volume manufacturing promises to improve product affordability. GSA will undertake an evaluation of next-generation electrochromic technology in 2014.

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

INTRODUCTION



A. Exterior of TC window installation

B. Interior of EC window installation

> *"Chromogenic windows are proving to be an effective means to control building solar heat gains."*
>
> —Doug Rothgeb, PE, CEM
> Building Operations Program Specialist
> Denver, Colorado
> GSA

What We Did

CONDUCTED 12-MONTH PILOT DEMONSTRATION IN DENVER, COLORADO

In the summer of 2011, GSA replaced existing single pane, clear glass windows on a second story, west-facing facade at the Denver Federal Center with 14 thermochromic and 8 electrochromic window systems. The pilot demonstration affected a 9,500 ft^2 perimeter zone of open office space, and enabled comparisons against a set of double pane, low-emissivity windows that had been installed along the same facade in 2005. The two chromogenic window types were tested over a year-long period ending in June 2012. Testing of the electrochromic windows included two phases: the first with automated controls only, and the second with a revised automated system and new manual override switches.

What We Measured

SOLAR RADIATION, HEAT TRANSFER, LIGHT TRANSMITTANCE, AND OCCUPANT COMFORT

To capture data on conductive heat transfer (U-Factor), solar heat gain (SHGC), and visible light transmittance, the test windows were fitted with indoor and outdoor sensors measuring solar radiation, illuminance, window surface temperature and window frame temperature. Because actual energy savings can vary greatly depending on the capacity and set-up of HVAC systems, the energy performance of these windows was not measured directly but instead modeled virtually using Windows 6 and EnergyPlus simulation software. Lighting energy use was not evaluated in this demonstration due to the absence of dimmable lighting controls. In addition to testing technical performance, the pilot assessment evaluated user visual and thermal comfort, satisfaction with the windows, and perception of indoor environmental quality through post-deployment occupant surveys. There is currently very little post-occupancy data for chromogenic windows; therefore, while of limited sample size, these surveys are especially useful as first indicators of occupant response.

PERFORMANCE SPECIFICATIONS
Whole Window Properties

SINGLE-PANE CLEAR GLASS	U-Factor	.80
	SHGC	.59
DOUBLE-PANE LOW-E	U-Factor	.48
	SHGC	.30
TC DOUBLE-PANE LOW-E	U-Factor	.48
	SHGC	.13 -.19
EC	U-Factor	.51
	SHGC	.13 -.43
ASHRAE 90.1-2010	U-Factor	< .55
	SHGC	< .40
ENERGY STAR	U-Factor	< .30
	SHGC	Any

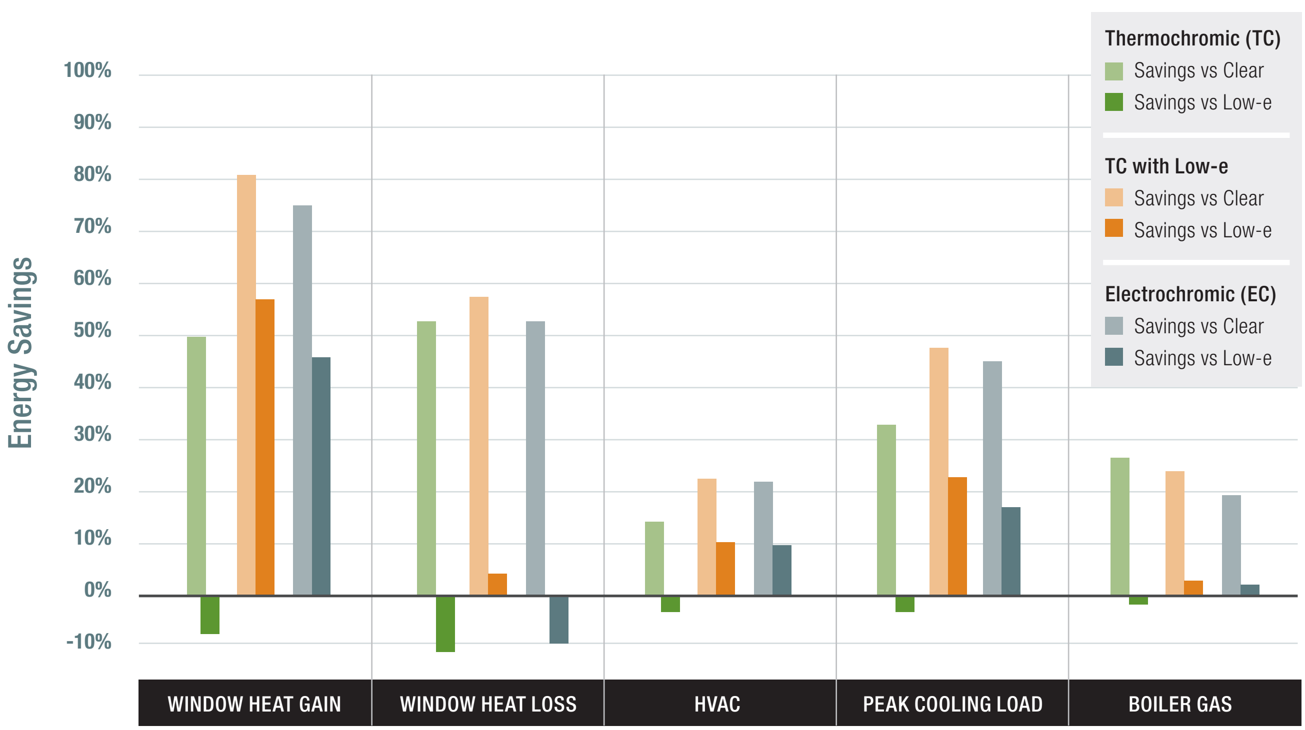
FINDINGS

CHROMOGENIC WINDOWS PROVE EFFECTIVE IN LIMITING HEAT GAIN While GSA's pilot evaluation of chromogenic windows found that the technology contributed little improvement in controlling heat *loss* compared with double pane, low-emissivity windows, it found that this technology is very effective in limiting heat *gains* due to its ability to dynamically regulate solar radiation. In the Denver test case, thermochromic and electrochromic windows respectively reduced window heat gain by 58% and 46% over the baseline low-e window, resulting in reductions of 10% and 9% in annual HVAC cooling electricity use.

DYNAMIC TINTING CAPTURES THE BENEFITS OF NATURAL DAYLIGHTING Occupants reported a diminished level of glare with both types of chromogenic windows, a benefit that improved further with the installation of user controls in the electrochromic case. While this effect can arguably be achieved more affordably with interior shades, field studies have shown that operable shades, once lowered, often remain that way regardless of exterior light levels. Because electrochromic windows are dynamically and automatically responsive to daylight, they are able to reduce the need for interior lighting by untinting without user action.

CHROMOGENIC WINDOWS PRESERVE OUTSIDE VIEWS BUT WITH SOME DISTORTION Occupant satisfaction with the visual impact of chromogenic technologies in the pilot demonstration was mixed. Both window types tint much darker than typical bronze-tinted windows, leading some occupants to comment on the distortion of outside views and weather patterns. In addition, the thermochromic windows were sensitive to details of surrounding surface geometry and ambient conditions which affected the appearance of the window: some areas were tinted while other areas remained clear.

Modelled energy savings comparing TC and EC vs clear and low-e



CONCLUSIONS

What We Concluded

DYNAMIC WINDOWS SHOW PROMISE IN ENERGY REDUCTION

GSA's pilot evaluation of chromogenic windows in Denver validated their potential to save HVAC energy via controlling heat gains, with thermochromic and electrochromic windows respectively showing 10% and 9% decreases in annual HVAC cooling electricity use compared to low-e windows. In a major retrofit scenario, this could result in further savings achieved with a smaller cooling/boiler plant. Additional electrical savings are likely in open floorplans, where the windows will support lighting that incorporates daylighting control technology. At the time of this report, these favorable findings were tempered by high material and labor costs; costs for insulating glass units without frame installation average \$40/ft^2 for thermochromic and \$61/ft^2 for electrochromic, compared to \$24/ft^2 for low-e. These market conditions have led to inconsistent findings in the costs and benefits of chromogenic windows against more readily available low-e windows. Installation costs for chromogenic windows are anticipated to stabilize as manufacturers, contractors, architects and engineers become more familiar with the new technology. Based on these findings, GSA is undertaking a further evaluation of electrochromic glazing in a high-rise curtain wall installation, in an open floorplan with lighting that adjusts in response to daylight. Results from this study are expected in 2015.

Lessons Learned

WHOLE-BUILDING SYSTEM DESIGN AND END-USER EDUCATION WILL CONTRIBUTE TO BETTER RESULTS

While there is no difference in labor associated with thermochromic window installation as compared with low-emissivity windows, set-up of electrochromic windows is more complex because their installation and commissioning require the expertise of electricians and building automation system engineers. Because the effectiveness of active dynamic windows is inextricably tied to HVAC and lighting system design, proper commissioning of control algorithms is particularly important to the performance of electrochromic windows. Calibrations may depend on factors including end user preferences for lighting level and glare control. Installation of electrochromic technology also requires monitoring and diagnostics strategies to detect, trend, and correct erroneous operations.

Inherent to dynamic windows is the trade-off between HVAC energy savings and occupants' desire for daylight. Facilities personnel need to understand both the design intent of the electrochromic windows and how to adjust settings to address occupant preferences without undermining energy conservation goals. Occupants, too, should be informed about window operation and energy-saving objectives. This understanding has been shown to contribute significantly to occupant satisfaction.

Reference above to any specific commercial product, process or service does not constitute or imply its endorsement, recommendation or favoring by the United States Government or any agency thereof.

These Findings are based on the report, "A Pilot Demonstration of Electrochromic and Thermochromic Windows in the Denver Federal Center, Building 41, Denver, Colorado," which is available from the GPG program website, www.gsa.gov/gpg

For more information, contact GSA's GPG program gpg@gsa.gov

Footnotes

[1] Arasteh, D., S. Selkowitz, J. Apte, Zero Energy Windows, Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings, August 13-18, 2006, Pacific Grove, CA, http://gaia.lbl.gov/btech/papers/60049.pdf

[2] 2010 Buildings Energy Data Book. US Department of Energy, Building Technologies Program, Energy Efficiency and Renewable Energy. Tables 1.1.1 and 1.2.3.

Technology for test-bed measurement and verification provided by RavenBrick and SageGlass.