Switchable windows demonstrated to provide increased view in offices

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

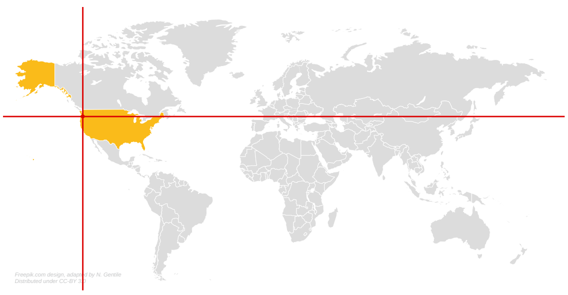
Transparent electrochromic windows increase user options for tuning their environment to satisfy personal preferences for daylight, view, and comfort

Low-emittance windows were replaced with variable-tint, electrochromic windows in forty private offices. 85% of the occupants preferred the electrochromic windows, citing increased view and visual comfort.

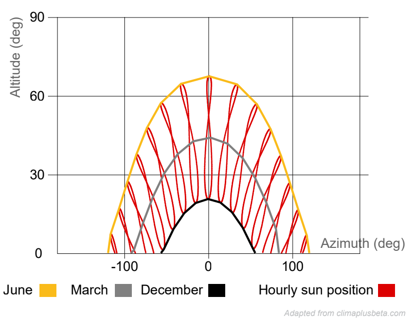
The project

The environment next to windows is the most variable of all areas in a building and yet is the most desirable due to proximity to outdoor views and natural light. Switchable electrochromic (EC) windows can temper broad fluctuations in solar radiation and daylight by modulating tint levels between clear and darkly coloured states based on a dimming signal from automatic or manually operated controls. With adequate control, the windows can reduce heating, cooling, and lighting energy use in buildings and provide daylight and transparent views to the outdoors. To better understand user satisfaction with this novel technology, a monitored demonstration of the technology was conducted on two floors of an eight-story, 29,000 m^2 office building (vintage 1953) in Portland, where EC windows were installed on the south facade (Fig. 1-3). The EC windows were controlled automatically to meet solar control, daylight, glare, and view requirements of office workers. The tint level could be manually overridden by the occupant at any time. Performance was compared to existing office conditions, i.e., dark tinted, dual-pane, low-emittance windows. Both the EC test and low-e reference

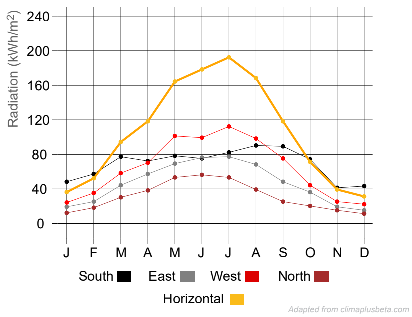
Figure 1. Exterior facade of the monitored commercial office building.



Location: Portland, Oregon, USA
45.50° N, 122.67° W



Sun path for
Portland, Oregon, USA



Global horizontal and vertical radiation for
Portland, Oregon, USA

IEA SHC Task 61 Subtask D

Monitored by **Luís L. Fernandes, Anothai Thanachareonkit,** LBNL
More info **Eleanor S. Lee**, Lawrence Berkeley National Laboratory, eslee@lbl.gov
https://facades.lbl.gov/demonstrations

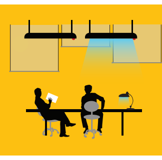


Figure 2. Outdoor view of the south façade with electrochromic (ec) and original (o) windows.

windows had indoor Venetian blinds. However, occupants in the test offices were deterred from using the blinds to assess the need for indoor shades (i.e., the blinds were tied in the fully raised position but could be untied at any time upon request). In both conditions, the existing fluorescent lighting was operated with a manual on-off switch and occupancy sensor. The installation occurred in Portland, Oregon – a northern city which is overcast during the winter and partly cloudy during the summer.

Monitoring

An assessment of energy use, comfort, and indoor environmental quality was based on continuous monitoring of outdoor and indoor environmental conditions in both the test and reference offices over a six-month, solstice-to-solstice period; time-lapsed luminance and infrared thermography imaging on select days; monthly surveys of venetian blind use; the facility's complaint log and surveys issued to occupants at the conclusion of the study. Performance was evaluated through simultaneous, parallel comparisons to the reference condition, which had similar space usage and layouts.

Energy

Annual lighting energy use in the 4.7 m deep private offices was estimated to be reduced from 9.37 to 5.96 kWh/m^2-yr (26%) due to greater availability of daylight from the EC windows compared to the dark tinted, low-e windows. In the EC normal automatic control mode, summer cooling loads on the EC test floors were increased by 2% compared to the reference floor because daylight admission was prioritized over cooling load control. Alternate tests were conducted to determine if the operational efficiency

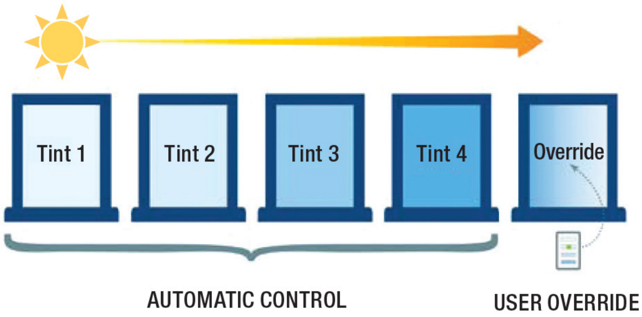


Figure 3. Illustration of EC window tint states.

Table 1. Visible transmittance (Tvis), solar heat gain coefficient (SHGC), and U-value (W/m^2-K) of EC window; Reference window: Tvis=0.15.

	Tint 1	Tint 2	Tint 3	Tint 4
Tvis	0.36	0.25	0.13	0.02
SHGC	0.43	0.28	0.16	0.09
U-value	1.65	1.65	1.65	1.65

of the air handler unit (and potentially thermal comfort) could be improved by minimizing differences in cooling load between the north and south zones of the building. Switching the EC windows to its darkest tint during sunny periods reduced solar transmission from 28 W/m^2 (reference office) to 3 W/m^2 (test office) per window area (89%), providing a more balanced load between zones. Trade-offs between daylight and solar control were evaluated by the facility managers and in the end, occupant preferences for more daylight won out, with thermal discomfort due to overcooling in the north perimeter zones addressed separately through recommissioning of the variable air volume boxes at the zonal level. Survey data indicated that occupants' thermal comfort on the south side increased during cold weather conditions.

Photometry

In terms of daylight quality, control of EC windows must also balance trade-offs between daylight admission (clear tint) and control of glare (dark tint). Glare perception is highly dependent on direction of view, type of task being conducted, position, size, and intensity of glare sources within the field of view, and sensitivity of the occupant to discomfort glare. Electrochromic windows can reduce luminous intensity but they can't block sunlight. Even at its darkest tint level, the luminance of the sun seen through the EC window can still exceed 1,000,000 cd/m^2, which can cause visual discomfort. In these instances, the occupant can use the Venetian blinds to control glare. In this study, the need for blinds was evaluated using periodic observations of Venetian blind position.

The EC windows in each private office were controlled as a single zone; i.e., all windows were switched to the same tint level. In response to occupant feedback, automatic tint levels were constrained to a narrower range (Tint 1-3, Table 1), with the darkest tint level available only through manual control. Occupants preferred daylight and

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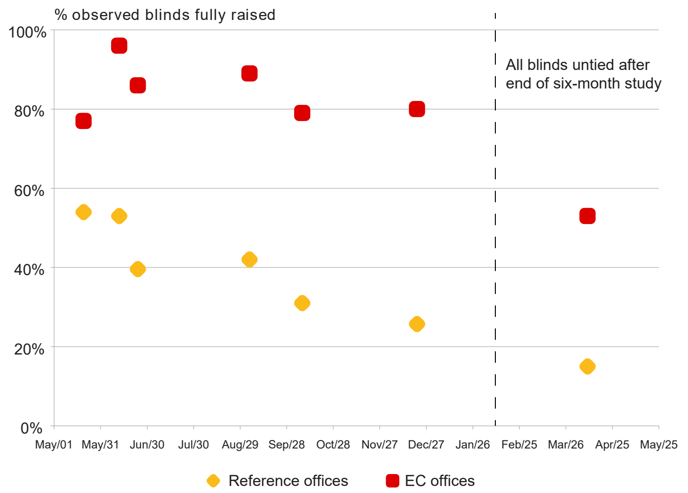

Figure 4. Percentage of Venetian blinds in fully raised position in reference and EC test offices before and after the six-month monitored period. After December, any remaining blinds were untied in the EC test offices.

views provided by light- to moderately-tinted EC windows. They controlled glare instead by using partially lowered blinds and individualized use of the darker EC tint level. Data revealed that manual override of automatic control occurred 11 times per weekday during the summer and three times per weekday during the winter across all 40 offices (six-month total monitored period; about half of the overrides were attributable to one office). When overridden, most commands were to darker tint levels when conditions were sunny and were about 10 minutes to one hour per day in duration. Venetian blinds were used in the offices but there were 40% less blinds lowered in the EC test offices compared to the reference offices (Fig. 4).

Discomfort glare levels were measured using high dynamic range (HDR) imaging on weekends with the blinds fully raised and with the full tint range permissible for automated control. During partly cloudy periods when the sun altitude was lower in the sky (from autumn to spring), discomfort glare levels ranged from "noticeable" to "intolerable" for occupant positions facing the window when both close to and further from the reference and test windows (Fig. 5). These data indicate that some occupants who chose not to lower their blinds accepted occasional glare discomfort, perhaps due to a stronger preference for daylight and views during the overcast and partly cloudy winter period. During sunny periods, discomfort glare levels were "intolerable" if the sun was in the field of view since the EC tint level was minimal (Fig. 7). Such times would warrant use of the blind or manual override.

Circadian potential

A detailed assessment of the non-visual effects of light on human health was not conducted in this study. However, time-lapsed HDR measurements performed for glare analysis on a single equinox day were used to assess whether melanopic light intensities due to daylight were sufficient to promote alertness in work areas. On a partly cloudy day (October 8th), the ratio of melanopic to photopic illuminance (M/P) was found to shift from M/P = 0.95 in the early morning and late afternoon when the EC window was clear to M/P = 1.3 from 10:30 AM to 4:00 PM when the EC window was fully tinted. A M/P ratio of greater than 0.9 indicates potential increased alertness due to transmission of shorter wavelengths, i.e., when the EC windows tint to a dark blue. Equivalent melanopic lux (EML) from daylight for views facing the unshaded EC window at a distance of 0.4 m and 1.8 m from the window was greater than 180 lx for 3.4 h and 1.2 h, respectively, for the period from 9:20 AM to 1:00 PM. The International Well Building Institute Standard (ver. Q4 2020) requires at least 200 EML of electric light between 9:00 AM and 1:00 PM (i.e., 4 h) year round. On this day, automated control prioritized solar and glare control, leading to low photopic and melanopic lux. The normal automated control mode, which prioritized daylight admission, increased daylight-driven EML.

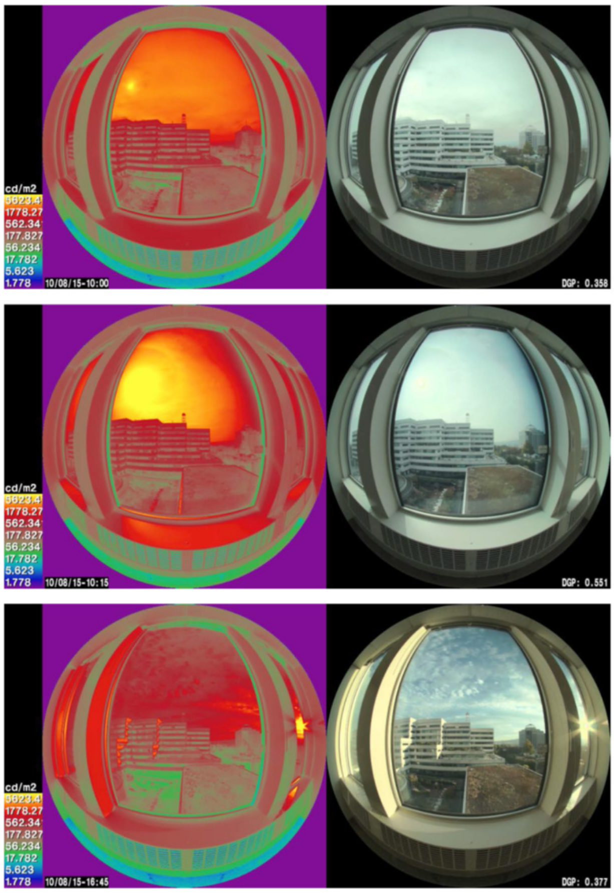

Figure 5. HDR image (left) and photographic view (right) from 0.4 m from the EC window, October 8th at 10:00 AM Tint 1 clear (top), 10:15 AM Tint 1 (middle), and 4:45 PM Tint 4 (bottom). discomfort glare was noticeable, intolerable, and noticeable, respectively.

User perspective

Pre- and post-installation surveys were issued to occupants in the test and reference offices. Of the 28 EC test and 38 reference office survey respondents, 48% and 43% faced the window, respectively, with the remaining facing the side or back wall. Regarding view, occupants agreed strongly that the outside view was sufficiently visible in the

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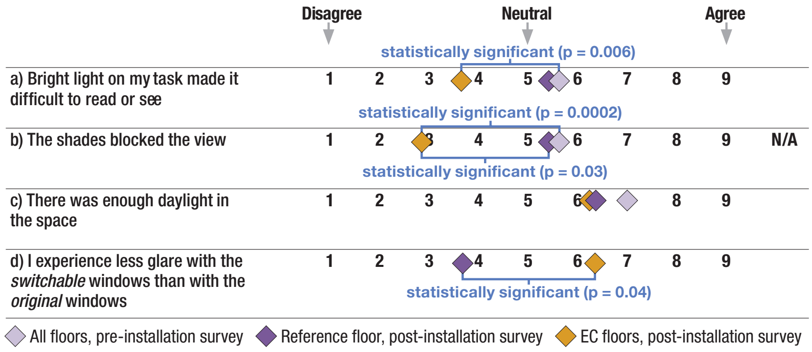

Figure 6. Occupant response on the reference floor (purple) versus EC test floor (orange).

Occupants were more satisfied with switchable windows than with the original windows.

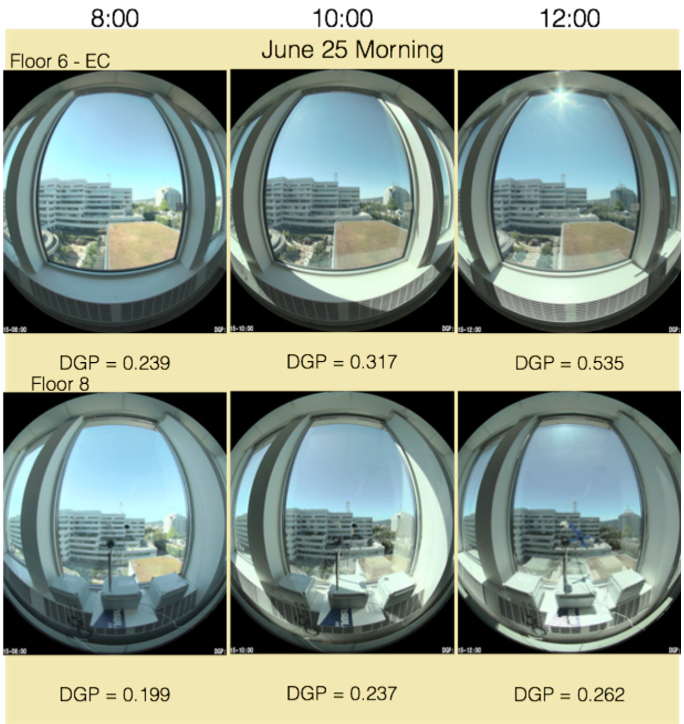

Figure 7. Discomfort glare levels in EC office (above) versus reference office (below) on a sunny day. Glare levels in the EC office were "intolerable" at noon due to the sun in the field of view. EC set to Tint 1.

EC test offices. At the conclusion of the six-month study, 30% of the blinds had been untied and there were 40% less blinds lowered in the EC test offices compared to the reference offices. Occupants in the EC offices also disagreed moderately that the blinds blocked the view while they agreed slightly in the reference offices (Fig. 6).

In terms of visual comfort, occupants reported that they experienced less glare in EC offices. This occurred despite the limit to moderate tint levels with automatic control. The darkest tint level could only occur with manual override and these overrides occurred infrequently. One possible reason for this result is that the Portland climate is predominantly cloudy so the bright sky, not the sun, is the primary source of glare. A moderate tint level is sufficient for controlling sky brightness.

Occupants reported that light levels were just below "just right" levels compared to reference office levels which were just above "just right". Perceived lack of sufficient light could be a result of a constraint that all windows in an office were zoned to be switched to the same tint level. EC windows can be controlled individually (e.g., some for glare or solar control, others for daylight), but this option was not implemented in this study. Another reason could be due to the narrow switching range of the EC window. Putting the EC coating on a dark tinted substrate is not recommended and was done in this study to match the existing glass.

Lessons learned

Daylight and views are essential in high performance buildings, as indicated by survey results which indicated that 85% of the occupants preferred electrochromic windows over the existing windows. This study underscored the importance of integrated design and control of dynamic building facades with respect to climate, occupant requirements, and facility management goals. Because windows have such a significant influence over occupant comfort and workplace satisfaction, it is critical that a dynamic facade be designed and controlled with enough flexibility to meet personal demands and preferences. Meeting workplace wellness and sustainability goals while minimizing operating costs will require finetuning of the EC automated controls in response to employee feedback. To maximize the full potential of EC windows, it will be important that facility managers educate occupants on the benefits and trade-offs of this novel technology.

Further information

Lee, Eleanor S., Luis L. Fernandes, Samir Touzani, Anothai Thanachareonkit, Xiufeng Pang, Darryl Dickerhoff, *Electrochromic Window Demonstration at the 911 Federal Building, 911 Northeast 11th Avenue, Portland, Oregon*, General Services Administration, Green Proving Ground Report, November 2016. https://eta-publications.lbl.gov/sites/default/files/gpg-portland-lee.pdf

Acknowledgements

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