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Subject responses to electrochromic windows

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Abstract

Forty-three subjects worked in a private office with switchable electrochromic windows, manually operated Venetian blinds, and dimmable fluorescent lights. The electrochromic window had a visible transmittance range of approximately 3–60%. Analysis of subject responses and physical data collected during the work sessions showed that the electrochromic windows reduced the incidence of glare compared to working under a fixed transmittance (60%) condition. Subjects used the Venetian blinds less often and preferred the variable transmittance condition, but used slightly more electric lighting with it than they did when window transmittance was fixed.
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Keywords: Electrochromic windows; Venetian blind use; Subjective response; Energy use

1. Introduction

Electrochromic windows exhibit a change in transmission while maintaining a transparent view when a small dc-voltage is applied to the window. Products are beginning to be introduced to the market. Although conventional windows are generally viewed favorably by occupants, they sometimes allow too much light, along with associated glare and excessive heat, to enter the space. Traditional methods for controlling the amount of light entering the space, such as shades or blinds, generally block the view as well, and may be awkward to control. Electrochromic windows provide a light control solution that avoids these problems. However, current electrochromic windows have potential problems of their own. The electrochromic windows we tested have a visible transmittance range, which is limited to approximately 3–60%. Even 3% transmittance may not be low enough to control glare and direct sun, while higher transmittances are desirable for daylight harvesting and view under lower light conditions [1,2]. The windows we tested are fairly small in size (approximately 0.9 m on the long side), change color as their transmittance changes, and take several minutes to change their transmittance over their full range. Larger electrochromic windows have been made, but not with such a wide transmittance range. No current electrochromic window has any directional properties. A blind can be tilted to block direct sun, while still allowing a partial view. Electrochromic windows reduce the transmission of light from all directions.

Electrochromic windows are an emerging technology and little has been published about their acceptability [3,4]. This research project was designed to answer several questions. The first was whether an office with electrochromic windows and blinds provides an acceptable and satisfactory work environment. The second was to determine whether, and under what conditions, the use of blinds is reduced. The third was to compare the operation of, and satisfaction with, two different control methods (algorithms) for the electrochromic windows. A final goal was to examine the energy and power use of electrochromic windows as compared to a standard window.

2. Experimental set-up

Electrochromic windows were installed in two rooms in the window systems testbed facility at the Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California (latitude 37°4′north). Both rooms were 3 m wide × 4.6 m deep and 3.4 m high (Fig. 1). The south wall of the rooms had electrochromic windows installed in a 3 unit wide × 5 unit high window grid, that ran from wall to wall, and from about 34 cm above the floor to a height of approximately 2.7 m. Each of the three window columns also had an operable Venetian blind (91.4 cm wide × 295 cm long with a 2.5 cm curved aluminum slat of matte white color). The mullions between the windows were approximately 7.6 cm wide and 6.35 cm high.

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Fig. 1. Perspective (left) and fisheye (right) of test room interior. The left view shows the columns of electrochromic windows at three different levels of transmittance: 5, 30, and 60%. The right view shows the window at 5%. The rooms were not furnished with a task desk lamp (shown in left figure) at the time of the tests.

The north wall contained a door and the other two walls were blank. The room contained desks along the south and west walls. A computer was placed on the west wall desk.

The lighting and control equipment and most of the physical monitoring of the testbed facility have been described in a previous paper [5]. Measurements included outdoor and indoor light measurements, outdoor irradiance, equipment wattages, control system data, and transmittance measurements of the windows. For this study, we added the Venetian blinds, and monitoring equipment to measure blind height and tilt. We also added indoor vertical illuminance and luminance sensors. All data was sampled and recorded at 1 min intervals.

The blind height measurement was made with a location sensor that consisted of a potentiometer and a cord on a spool (Micro Epsilon, WDS-5000-Z200-CA-P), and the tilt measurement was made with a tilt/accelerometer sensor that detected the angle from horizontal (VTI Technologies, model SCA610-CB1H1G). The blind sensors were calibrated against a visual inspection of heights and tilts. The standard deviations of the fits from the visually measured values was $\pm 5^{\circ}$ for blind tilt (range -90° to $+90^{\circ}$; with a positive value, one can see the ground from the interior), and ± 0.1 for blind height (range 0–10 for blind all the way down to all the way up).

The vertical illuminances were made with a Licor illuminance sensor centered horizontally on the wall and located 122 cm above the floor. The luminance measurements were made by placing a Licor in a box, adjacent to the illuminance sensors, with a front opening that allowed only the surface of interest to be seen by the photosensor. The illuminance on these shielded sensors was scaled by the configuration factor of the opening to give the average luminance [6]. Both amplification and shielding of the Licor outputs introduces possible noise and error into these measurements. The raw global illuminances were therefore calibrated against values measured by a Minolta T-1 illuminance meter, while the average luminances were calibrated by measuring a grid of points in the field of view with a Minolta LS-110 1/3° spot luminance meter under stable and relatively even lighting conditions. Simple linear fits precise to 4% were derived for the two measurements. These fits were used to convert the raw values to final illuminances and luminances.

The work plane illuminance was determined by a photodiode sensor mounted at the level of the fluorescent lights looking down with a 60° cone of view. Fluorescent power was correlated to the work plane illuminance at night and was then used to provide a measure of the fluorescent lighting levels.

In addition to physical measurements, the experiment also measured subjective responses under conditions as close to normal working conditions as we could make them. Bathroom facilities were available in a room immediately across a one-way, one-lane street from the testbed. An experimenter was present in the hallway, and was available if needed to help subjects' set-up any network connections that they needed on the computer. There was a phone and several pens in the test room. The hall contained a water cooler and a networked printer. Subjects doing computer work had the choice of a recent model Apple or Windows computer in the test room, or could bring their own portable computer. The Windows monitors were 43 cm liquid crystal display (LCD) (Samsung Syncmaster 170N) with a maximum luminance of 250 cd/m^2. The display used with the MacIntosh was a 43 cm LCD (Princeton LCD17M-BLK) with a maximum luminance of 140 cd/m^2. Neither monitor exhibited sharp reflections, so both were significantly superior to older cathode ray tube (CRT) type monitors in providing visibility under daylight conditions.

3. Experimental procedure

Subjects spent the first part of the experimental session being introduced to their surroundings and the experiment and setting up to do work. They were told that the ''experiment'' would consist of three sessions, so that we could test three different control algorithms with the electrochromic windows. The order of the three control algorithms was varied over the different subjects. The subjects were told that at the end of each session they would be asked to fill out a questionnaire about their impressions during the session. The questions for each session were identical, except that during the last session several questions were added about all three sessions, and a separate final questionnaire asked for comments on their overall experience, the questionnaire suitability, and the experimental procedure (see parts E and F of the questionnaire in