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Retrofit electrochromic glazing in a UK office

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Abstract

Electrochromic (EC) glazing is now considered a viable alternative to fixed transmittance glazing. It has the potential to enable occupants to control daylight glare and solar heat gain without the use of blinds or external shading devices, giving users more access to daylight with all its inherent benefits. Furthermore, EC glazing can reduce energy consumption by decreasing cooling loads and electric lighting usage.

Most research to date has studied the effects of EC glazing in scale models, computer simulations and full scale test rooms, and some of these studies have included human participants. However, there is a general lack of understanding regarding the performance and suitability of EC glazing in real-world working environments.

A case study of the first UK retrofit application of EC glazing is being conducted in two adjacent offices in a university campus building. The offices are occupied by administration staff and have large southeast-facing windows. The existing double glazed units were replaced with commercially-available EC glazed units in 2012. Over a period of more than 18 months, the rooms were monitored intensively to record the effect of the EC glazing on both the physical room environment and the occupants themselves. A large amount of data from the monitoring programme is currently undergoing detailed analysis. Initial findings emerging from the installation and post-installation period are described in this paper.

Key Words:

Electrochromic glazing, smart windows, visual comfort, daylighting, daylight glare.

1. Introduction

Buildings with highly-glazed facades often suffer from problems of visual discomfort and solar gain. Typically, internal blinds are used to control solar ingress, but these are regularly left closed for extended periods [Van Den Wymelenberg, 2012], leading to reduced access to daylight and views for occupants. External shading devices are often employed as a solution to control solar overheating as well as visual discomfort. However, a fixed shading device rarely provides optimal control for solar ingress because of the wide extent and constant variation in sun position. A "heavy" *brise soleil* can be an overpowering presence in façade architecture, often appearing as an afterthought rather than an integral feature of the building design. A variable shading device is likely to perform better than a fixed *brise soleil*, but these are rarely considered due to increased cost and maintenance issues compared to static devices.

Electrochromic (EC) glass changes transmittance in response to a small applied voltage (less than 5 volts DC). An EC window can be operated automatically or manually to control light penetration, without compromising the view out. By providing unobtrusive dynamic shading in this way, EC glazing has significant potential to improve daylighting and energy use in new and existing buildings.

Unsurprisingly, EC glazing has attracted significant research since its inception in the 1980s [Lampert, 1984; Svensson & Granqvist, 1984]. However, most of these studies have been simulation-based [Sullivan et al, 1994; Moeck et al, 1998] or lab-based using scale models or full-scale rooms [Piccolo et al, 2009; Lee et al, 2006; Clear et al, 2006; Zinzi, 2006; Lee at al, 2012 and others]. Only a few of these have included a systematic assessment of the experience of human users of the technology [Clear et al, 2006; Zinzi, 2006; Weinold, 2003]. However, those that did include human participants were lab-based, so that participants only experienced the technology for short periods of time (i.e. hours), and not in their normal work setting.

This paper describes a case study of the retrofit application of EC glazing in an administration office of a university campus building in the UK. The case study has a number of novel features:

- It is the first installation of EC glazing of its kind in the UK.
- At the time of writing, it is one of only two published studies of EC glazing that has been carried out in a real-world setting (see also Lee at al, 2012).
- It utilises high dynamic range (HDR) photography as part of the physical monitoring of the room luminous environment.
- It employs a mixed-methods approach, designed to capture both the subjective experience of occupants and the physical effects on the room environment.

2. EC glazing operation

In a double-glazed electrochromic (EC) window, a nanometers-thin coating on the inside surface of the outer pane allows the glass to

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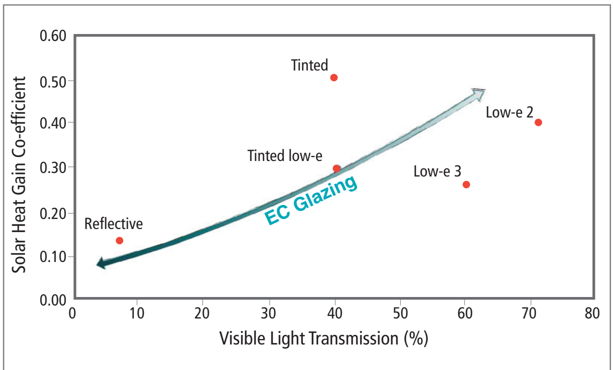

Figure 1: The dynamic properties of EC glazing compared with traditional glazing types. *Image reproduced with permission from SAGE Electrochromics Inc.*

change transmittance in response to a small applied voltage. The electrochromic coating is made up of several layers that essentially operate like a battery, with electrons moving between layers when the voltage is applied, effecting a change in overall glazing transmittance. The EC windows at the focus of this study were manufactured by SAGE Electrochromics Inc in 2012. The visible transmittance of the glass varies from 62% in the fully bleached (un-tinted) state to 2% in the fully tinted state, with two intermediate states (20% and 6%).

Figure 1 illustrates the dynamic properties of EC glazing when compared with traditional static glazing types. Many contemporary glazing products can perform very well under certain external conditions. However, when conditions change, other devices are necessary to control the internal enviornment satisfactorily. Thus, the ability of EC glazing to adapt to changing external conditions without the use of moving parts is clearly a key advantage of the technology.

The control stimulus can be linked to any sensor input, depending on the type of control desired. For example, the trigger for tinting the window could be an increase in internal room temperature, internal light level, or, as in this case, external light level on the façade. The EC window is normally operated automatically, and can also be manually controlled using the wall-mounted switch shown in Figure 2.

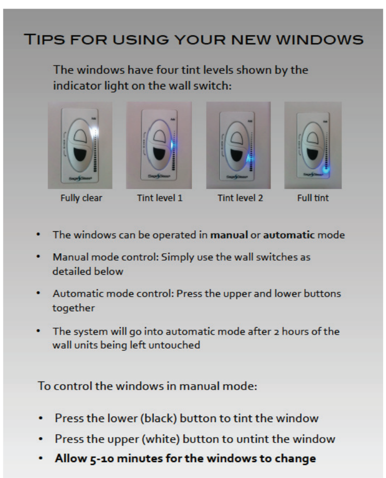

Figure 2: EC window wall switch (above left) and a wall sign mounted in the rooms explaining how to use the switches (right).

3. Case-study outline

The case study is centred on two open plan offices with large southeast-facing windows. In 2012, the windows were replaced with commercially-available double-glazed EC windows (described in Section 2). The windows are made up of several panes, and the control system is zoned so that individual panes (or pairs of panes in the case of the larger windows) can be controlled independently. Figure 3 shows the interior of the two rooms before and after the EC glazing installation.

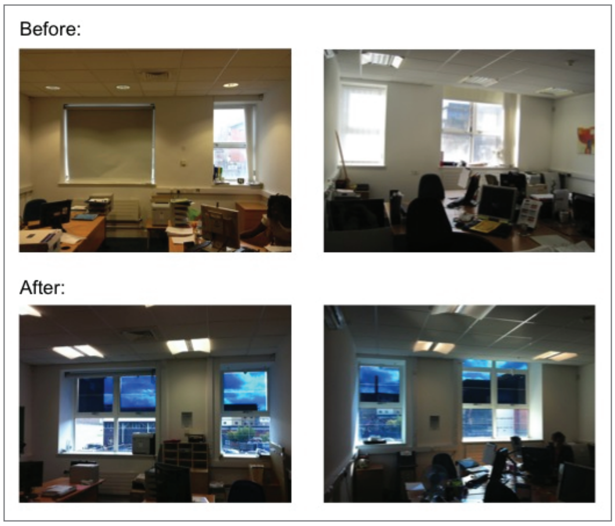

Figure 3: The interior of the case study rooms before and after the EC glazing retrofit. (Note that in the "after" photos the electric lighting is switched on because the daylight-linking control system had not yet been commissioned).

Each room accommodates four people whose work is administrative in nature, and who are office-based for most of their working hours. The two rooms share three windows between them, with a partition down the centre of the middle window. The exterior is shown in Figure 4.

The study assesses the direct impact on the visual and thermal environment as well as end-user experience of the technology. A programme of monitoring was undertaken for over 18 months to

Figure 4: The exterior façade of the two case study rooms.

ensure that a range of seasons and sky conditions were included. The main study participants are occupants of these rooms.

4. Method

A mixed methods approach was used to assess the impact of the EC glazing on the physical environment (non-subjective) as well as the experience of the room occupants (subjective).

Subjective measures

The main challenge of the subjective study design was to achieve a balance between minimising participant burden while capturing good-quality information at regular enough intervals. The need to minimise intrusion to occupants is particularly important in this case due to the small number of participants. The study design is layered, with each layer having a different density of observation. This ranges from a daily but coarse-grained evaluation of the windows ("good", "neutral", "bad"), to a more detailed but less frequent online questionnaire. In addition, a one-to-one interview was carried out every three months, in which a deeper exploration of the subjective narrative was possible. The subjective study design is explained in more detail in a previously published work [Kelly et al. 2012].

Each layer of observation has been carefully designed with the aim of collecting data at a useful level of depth and frequency to enable a realistic picture of the users' experience to emerge, and so provide the basis for a meaningful analysis.

Non-subjective measures

In parallel to the subjective assessments, a set of repeated meausrements were made to capture the impact of EC glazing on the physical environment of the offices.

High Dynamic Range (HDR) imaging with a fish-eye lens was used to capture and quantify the luminous environment. Figure 5 shows a sample HDR image taken in one of the case study rooms before the EC window retrofit. As it was not practical to locate the HDR cameras at the occupants' eye position, the cameras were positioned as close as possible to the participants head position, at seated eye height. Where possible, one camera was shared between two participants, e.g. between adjacent workstations.

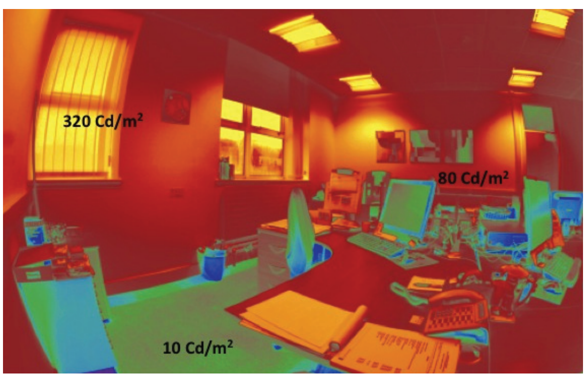

Figure 5: A test HDR image taken in one of the offices before the EC window installation.

As well as capturing visual scene luminance via HDR, the other physical measurements are as follows:

1. Room temperature
2. Air conditioning status
3. Heating status
4. Interior illuminance
5. EC window status
6. EC window manual overrides
7. Blind position
8. Electric lighting energy use
9. EC window energy use
10. Weather data via a local weather station

It should be noted that, although electric lighting current has been monitored as part of this study, the focus is on the user experience of EC windows, and as such the effect on electric lighting energy use will not be investigated in depth. The potential of EC glazing to reduce electric lighting energy use, as well as cooling load, has been studied previously by others, e.g. (Lee et al., 2006).

5. Initial findings

As a result of this case study, a large and varied dataset has been obtained, the detailed analysis of which is currently underway. Nonetheless, some findings have already emerged, and these are outlined below.

Installation

From the point of view of installation, a key difference between EC windows and traditional windows is the need for wiring (power and communications). The cables are low-voltage and there is nothing particularly novel or challenging about the wiring required … it simply needs to be scheduled as part of the installation process. For openable windows (as they are in this case), the wires to the EC glazing should of course be at the hinged side. For the installation described here, the offices have a partition wall that divides the central EC window frame. Despite not being the most straightforward of scenarios for the deployment of a novel glazing technology, the windows were installed in two days, which seems reasonable even for traditional double-glazed windows of the same size. Commissioning of the control system was carried out as each unit was installed, and was completed within the week of the installation. The control system ran with default settings for the first few months, after which time the settings were adjusted in response to feedback from occupants and observations of the system operation.

Room layout

Roller blinds were left in place after the EC window installation. They were fully retracted when the occupants moved back into their office after the work was completed. It was interesting to note that the occupants in one room did not use the blinds at all until around the beginning of December, and then only rarely. Because of the orientation of the façade, at low sun angles the solar disc is visible in the middle of the windows. For occupants facing the

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windows, this has produced some visual discomfort even with the EC windows at full tint. Under these conditions, the minimum transmittance of 2% was not enough to control glare adequately for some occupants, though the sensitivity to this may depend on individual sensitivities. This finding supports previous studies [Lee et al, 2002] which indicated that a minimum transmittance of 1% was desirable. (It should be noted, however, that SAGE's latest product achieves a minimum transmittance of 1%, which should provide better glare control for occupants with a direct view of the window).

Occupants who sit with their backs to the windows reported fewer instances of visual discomfort. This finding suggests that space layout could be optimised to avoid any requirement for blinds in an office with EC glazing, e.g. occupants could be positioned so that they are not normally facing a window, and/or that they can easily change their position to avoid direct sun in their eyes. In any case, from a glare control point of view, it is good practice to locate office work stations perpendicular to windows where possible.

View and connectedness to outdoors

Feedback from participants suggested that they value the ability to see through the windows continously. Theirs is an urban view, comprising a parking area, a road and nearby buildings. During interviews, they commented positively about the ability to see people and vehicles coming and going. Before the installation of the EC windows, participants indicated that with the blinds drawn, the room had a tendency to feel "closed in". Several participants observed that when the windows are tinted, the sky looks darker than it is in reality, giving the false impression that it might rain, for example. However, the windows should not normally be tinted under cloudy conditions, and if so, only briefly, so this may not be a significant issue for other installations.

Window tinting, daylight spectrum and colour

When questioned about their window-tint preferences in interviews, several participants indicated that they preferred to have the lower row of window panes (which are in their eye-line when seated) un-tinted, except when direct sun was visible through those panes. There are likely to be several factors at play in this preference, including a desire for an 'un-darkened' view to outside, and/or a perception that daylight that is not filtered through tinted glass is more natural.

To explore the second issue in more depth, a hypothesis was put forward: If at least one pane of the EC windows is not tinted, the resultant spectrum of daylight in the room is close to that of a room with completely un-tinted windows. A set of field measurements was made of daylight spectra in the case study room under various tint-pane combinations. This was compared with a set of theoretically modelled spectra, with very good agreement, thus supporting the hypothesis. This work is described in detail in a paper to be published by Lighting Research & Technology, Mardaljevic et al (2014).

Other implications

Latitude is obviously a key factor; in a more southerly location with higher year-round sun angles, it seems likely that the need for blinds could be significantly reduced or completely eliminated. The findings also indicate that EC glazing could be particularly effective when used in sloped/horizontal glazed openings such as large glazed roofs or rooflights.

6. Conclusions

A large data set has emerged from the 18-month monitoring campaign undertaken as part of this case study. This includes qualitative and quantitative data; measured data from the physical room environment and self-reported data from human participants. The process of retrofitting EC glazing into a typical UK office and the subsequent settling-in period has already highlighted several practical considerations which might be useful for future adopters of the technology. Detailed analysis of the data collected during the monitoring period is currently being undertaken, and it is anticipated that this will increase our understanding of the effect of EC glazing on its end users.

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