
RETROFIT ELECTROCHROMIC GLAZING IN AN OPEN PLAN OFFICE: A CASE STUDY

R. Kelly¹, B. Painter¹, J. Mardaljevic² & K. Irvine¹

¹ Ruth Kelly, De Montfort University, UK
P11237076@myemail.dmu.ac.uk

¹ Birgit Painter, De Montfort University, UK
bpainter@dmu.ac.uk

² John Mardaljevic, Loughborough University, UK
j.mardaljevic@lboro.ac.uk

¹ Katherine Irvine, De Montfort University, UK
bpainter@dmu.ac.uk

Abstract: Electrochromic (EC) glazing is emerging as an alternative to fixed transmittance glazing. It has the potential to enable occupants to control daylight glare without the use of blinds, giving users more access to daylight with all its inherent benefits. Furthermore, EC glazing could reduce energy consumption through a reduction of electric lighting usage and solar heat gain.

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 have been replaced with commercially available EC glazed units. The monitoring campaign will cover a period of at least 12 months and use a mixed methods approach in order to assess the effect of the EC glazing on the luminous environment and the subjective experience of the room occupants.

The research will explore whether EC glazing can improve visual comfort for users when compared with traditional double-glazing and manually controlled blinds.

Keywords: 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, such as brise soleil, 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.

In a double-glazed electrochromic (EC) window, a coating on the inside surface of the outer pane allows the glass to change transmittance in response to a small applied voltage. The 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.

Figure 1 illustrates the dynamic properties of EC glazing when compared with traditional static glazing types. Glazing materials with fixed properties can cope well with some conditions but not others; a material such as EC glazing which can change its properties to respond to changing conditions is obviously desirable in contemporary architecture.

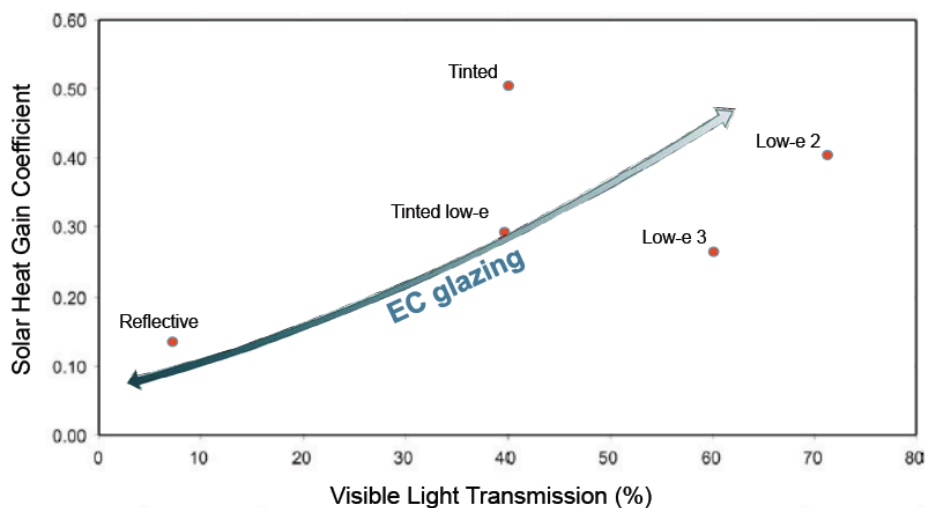


Figure 1 The dynamic properties of EC glazing compared with traditional glazing types
Image courtesy of SAGE Electrochromics Inc.

2. Research background

The discovery of the electrochromic properties of transition metal oxides is widely attributed to the work of Deb and colleagues in the 1960s and 70s [Deb, 1973]. The idea of electrochromic glazing as a novel fenestration material that could improve building performance began to appear in publications around the mid 1980s [Lampert, 1984; Svensson & Granqvist, 1984]. Such windows are often referred to as “smart” windows [Granqvist, 2012].

Early research focussed on computer simulations that signalled the potential benefit of EC glazing [Sullivan et al, 1994; Moeck et al, 1998]. In the early 2000s, physical studies of EC glazing prototypes began to emerge; a combination of reduced scale models [Piccolo et al, 2009; Piccolo 2010], and full scale test rooms [Lee & DiBartolomeo, 2002; Lee et al, 2006; Clear et al, 2006; Zinzi, 2006; Lee et al, 2012].

These studies indicate that EC glazing holds significant potential as a means of improving daylighting and lowering energy consumption through reductions in lighting and air conditioning use. However, as with any green technology, its success is heavily dependant on the level of acceptance of building occupants. It is also imperative to evaluate specific subjective effects of EC glazing, such as actual visual comfort, *i.e.* not just calculating predicted visual comfort. Therefore, research that includes human participants carrying out their normal, everyday tasks in their usual workplace is much needed in this field.

Two of the studies mentioned above included human participants and thus an assessment of the subjective effects of EC windows: Clear et al in 2006 and Zinzi in 2006. In each of these studies, participants ($n=43$ and $n=30$ respectively) were invited to a test room to carry out typical office work tasks at a desk (e.g. reading, using a computer) for short periods, and asked to complete a questionnaire on site. Whilst these studies provide the valuable insights into the subjective experience of would-be occupants, they were limited by their nature as lab-based studies. It is also notable that these studies were carried out in climate regions which are cooling- rather than heating-dominated (California, US, in the case of Clear et al. and Rome, Italy, in the case of Zinzi).

The results of Clear et al's study indicated a good level of user acceptance, with users using blinds less when combined with EC glazing compared with a clear double glazed window. Results also suggested that a lower visible transmittance than the 3% minimum for that glazing was necessary for the EC glass to be able to control direct sun satisfactorily under the worst case conditions, *i.e.* direct visibility of the solar disc. The EC glass used in Clear's experiment had a minimum visible transmittance of 3%. The finding supports previous studies [e.g. Lee et al, 2002] which indicated that a minimum transmittance of 1% was desirable. Clear's work also noted that the ability to control individual window panes separately would be beneficial.

Notwithstanding the worst case condition, Zinzi's study also found positive performance attributes for EC glazing. However, his results raised the issue of switching speed, *i.e.* the time taken for the window to clear or tint, and in particular the latter. The glazing used in Zinzi's study took about 12 minutes to complete the transition, and this was cited by a number of participants as being a problem.

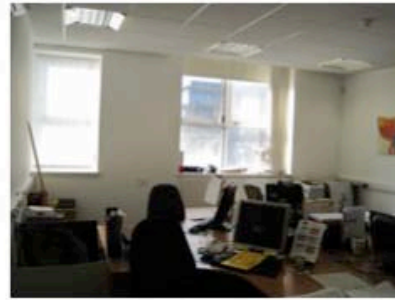
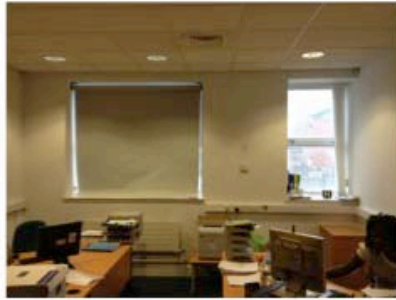
Aside from one recent study [Lee et al, 2012], there do not appear to be any studies of real-world applications of EC glazing, *i.e.* in everyday workplace settings rather than laboratories or 'test rooms'. The aforementioned study investigated the effects of EC glazing in a conference room in Washington DC, US. This work begins to address the dearth of real-world research into EC glazing, and also the lack of longitudinal studies into the application of the technology, as it reports on results obtained over six months of measurement. However, the transient occupancy patterns ruled out a systematic evaluation of the subjective impacts.

It is evident from the literature that a study of EC glazing in a real-world application, that includes an assessment of subjective experience of occupants over a long term period, is needed to further our understanding of this technology. This paper outlines a study now in progress which addresses these aspects.

3. Case Study Outline

The case study is centred on two open plan offices. The rooms have large southeast facing windows, which have been replaced with double-glazed EC panels, manufactured by SAGE Glass – the first installation of its kind in the UK. Each double-glazed unit has an electrochromic coating on surface 2 (inside surface of exterior pane). The visible transmittance of the glass varies from 62% in the fully bleached state to 2% in the fully tinted state, with two intermediate states (20% and 6%). The glazing can be controlled automatically (from a range of sensor inputs) or manually using locally mounted wall switches (see Figure 3). 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 2 shows the interior of the two rooms before and after the EC glazing installation.

Before:



After:

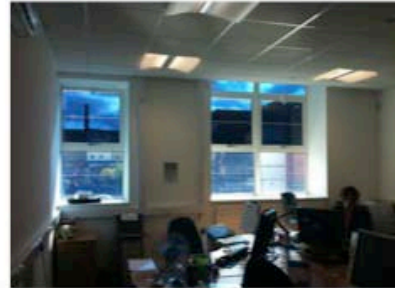


Figure 2 The interior of the case study rooms before and after the EC glazing retrofit

Each room accommodates four people whose work is administrative in nature, and who are office based for the majority 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.



TIPS FOR USING YOUR NEW WINDOWS

The windows have four tint levels shown by the indicator light on the wall switch:

Fully clear Tint level 1 Tint level 2 Full tint

- The windows can be operated in **manual** or **automatic** mode
- **Manual mode control:** Simply use the wall switches as detailed below
- **Automatic mode control:** Press the upper and lower buttons together
- The system will go into automatic mode after 2 hours of the wall units being left untouched

To control the windows in manual mode:

- Press the lower (black) button to tint the window
- Press the upper (white) button to untint the window
- **Allow 5-10 minutes for the windows to change**

Figure 3 EC window wall switch (left) and a wall sign mounted in the rooms explaining how to use the switches (right).

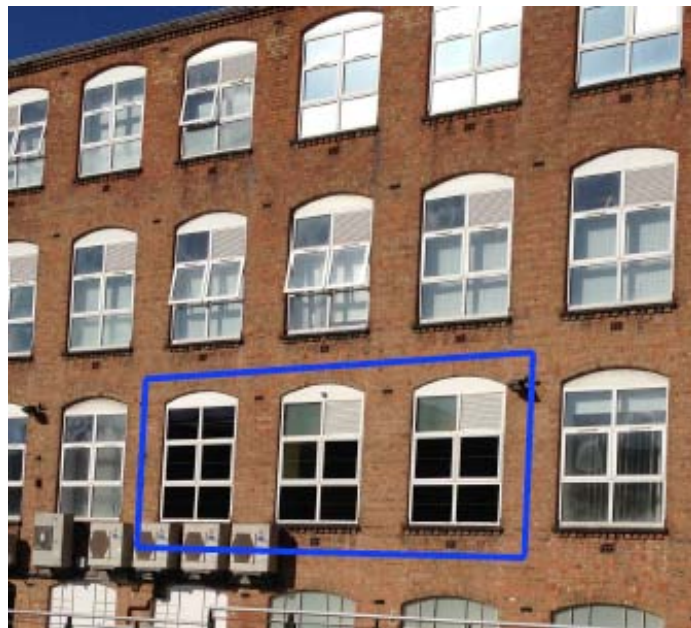


Figure 4 The exterior façade showing the windows of the two case study rooms

The study will assess the direct impact on the visual and thermal environment as well as end-user experience of the technology. A programme of monitoring began towards the end of 2012 and will continue for at least 12 months to ensure the full range of seasons and sky conditions are included. The first 6 months will run as the test condition, i.e. EC glazing (with manual blinds when necessary). The second 6 months will run as the reference condition, created by setting the EC glazing to be continuously un-tinted (as a proxy for clear double glazing) and allowing full use of manual window blinds. The main study participants are occupants of these rooms, and therefore will be exposed to both conditions. As such, this is a within-subject enquiry.

4. Method

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

Subjective measures

The main challenge of the subjective study design is to achieve a balance between minimising participant burden whilst capturing good quality information at regular enough intervals. The need to minimise intrusion to occupants is particularly important here 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 is carried out every quarter, in which a deeper exploration of the subjective narrative is 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 data [is](#) being gathered to capture the impact of EC glazing on the physical environment of the offices.

High Dynamic Range (HDR) imaging with a fish-eye lens is being used to capture and quantify the luminous environment. Figure 5 shows a sample HDR image taken in one of the case study rooms. It is not practical to locate the HDR cameras at the occupants’ eye position, so the cameras will be positioned as close as possible to the participants head position, at seated eye height. Where possible, one camera is shared between two participants, e.g. between their head positions. Test images taken from the actual point of view of each occupant will allow comparison and the application of a factor for correction. The software tool EvalGlare will be used to predict discomfort glare in the visual scene. These data will then be compared with the subjective experiences of the occupants.

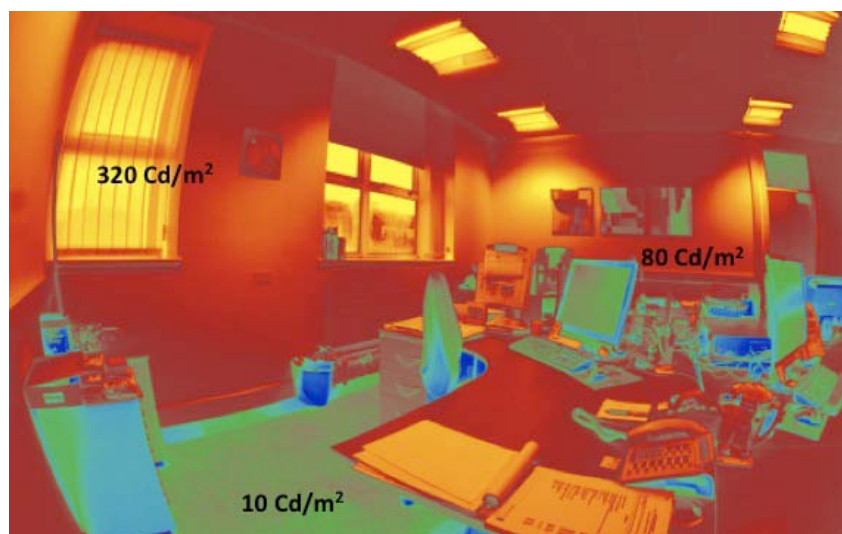


Figure 5 A test HDR image taken in one of the offices

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

In addition, external weather data will be accessed via a local weather station to give context to the interior measurements and assist with data analysis.

5. Initial Findings

The process of retrofitting EC glazing into a “typical” UK office has revealed a number of potential issues for future installations:

Installation

Unlike ordinary windows, the installation of EC glazing requires wiring to be carried out as part of the installation. The cables are low voltage/power, 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 the wires to the EC glazing should of course be at the hinge. 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 majority of the issues encountered during the installation were quickly resolved.

Sensor position

The EC windows are controlled by illuminance sensors, mounted just inside the window looking out. One significant implementation issue relates to the positions of light sensors on openable window sections. Each control zone needs its own sensor, but all the middle panes are openable, so sensors could not be mounted along the lower glazing bars. Therefore they were mounted upside-down along the window head/upper glazing bar. This sensor position is less than optimal, as it effectively means that the sensors are “looking” at the ground instead of the sky. The control setpoints for these zones have been adjusted to compensate for this, but for future installations this arrangement could be improved upon. If individual pane/row control is desired, one should think carefully about where sensors can be accommodated, especially if windows are openable. A sensor that is physically smaller, and possibly built in to the window frame, could also be a solution. Note that none of this is an issue if the windows are controlled as an ensemble by an external, façade mounted sensor. Such a sensor was also installed and its performance versus the individual window sensors will be evaluated as part of the study.

Room layout

Roller blinds were left in place on the larger windows 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. At low sun angles, the solar disc is visible in the middle of the windows. For occupants facing the windows this has produced occasional visual discomfort even with the EC windows at full tint, though the sensitivity to this may depend on the particular occupant. In contrast, occupants who sit with their backs to the windows have reported that they can tolerate direct sun on their screens and work satisfactorily when the windows are fully tinted. This finding suggests that space layout could be optimised to avoid any requirement for blinds in an office with EC glazing, e.g. occupants should 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.

[View & connectedness to outdoors](#)

[Initial feedback from participants suggests that they value the ability to see through the windows continuously. There 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, and even on being able to see what little wildlife there is to be seen, in the form of a bird on a rooftop. Before the installation of the EC windows, participants indicated that with the blinds drawn, the room had a tendency to feel "closed in".](#)

[This finding emphasises the importance of a view out, regardless of whether or not it is considered picturesque, and on the potential of EC glazing to enhance the wellbeing and visual comfort of occupants by allowing a continuous view.](#)

Other implications

Latitude is obviously another key factor here. 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 very effective when used in sloped/horizontal glazed openings such as large glazed roofs or rooflights.

6. Summary

The results of this study are expected to provide a valuable data set that combines real-world experiences of the implementation of EC glazing in a retrofit application, the physical effects of the technology on the test rooms, and the subjective experiences of the occupants. These data will be linkable to a wide range of sun positions and sky conditions and thus will provide an indication of the applicability of EC glazing in northern European latitudes.

7. Acknowledgements

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References

- R.D. Clear, V. Inkarorjrit, E.S. Lee, Subject responses to electrochromic windows, *Energy and Buildings* 38 (2006) 758-779.
- S. K. Deb, Optical and photoelectric properties and colour centres in thin films of tungsten oxide, *Philosophical Magazine*, Volume 27, Issue 4 (1973).
- C. G. Granqvist, Oxide electrochromics: An introduction to devices and materials, *Solar Energy Materials & Solar Cells* 99 (2012) 1-13.
- R. Kelly, J. Mardaljevic, B. Painter & K. Irvine, The long-term evaluation of electrochromic glazing in an open plan office under normal use: project outline, *Proceedings of Experiencing Light 2012*, Eindhoven, The Netherlands.
- C. M. Lampert, Electrochromic materials and devices for energy efficient windows, *Solar Energy Materials & Solar Cells* 11, Issues 1-2, (1984) 1-27.
- E.S. Lee, E.S. Claybaugh, M. LaFrance, End user impacts of automated electrochromic windows in a pilot retrofit application, *Energy and Buildings* 47(2012) 267-284.
- E.S. Lee, D.L. DiBartolomeo, Application issues for large-area electrochromic windows in commercial buildings, *Solar Energy Materials & Solar Cells* 71 (2002) 465-491.
- E.S. Lee, D.L. DiBartolomeo, S.E. Selkowitz, Daylighting control performance of a thin-film ceramic electrochromic window: Field study results, *Energy and Buildings* 38 (2006) 30-44.
- M. Moeck, E.S. Lee, M.D. Rubin, R.T. Sullivan, S.E. Selkowitz, Visual quality assessment of electrochromic and conventional glazings, *Solar Energy Materials and Solar Cells* 54 (1998) 157-164.
- A. Piccolo, Thermal performance of an electrochromic smart window tested in an environmental test cell, *Energy and Buildings* 42 (2010) 1409-1417.
- A. Piccolo, A. Pennisi, F. Simone, Daylighting performance of an electrochromic window in a small scale test-cell, *Solar Energy* 83 (2009) 832-844.
- A. Piccolo, F. Simone, Effect of switchable glazing on discomfort glare from windows, *Building and Environment* 44 (2009) 1171-1180.
- R. Sullivan, E.S. Lee, K. Papamichael, M. Rubin, S. Selkowitz, Effect of switching control strategies on the energy performance of electrochromic windows, *Proceedings of SPIE International Symposium on Optical Materials Technology for Energy Efficiency and Solar Energy Conversion XIII*, April 18-22, 1994 in Friedrichsbau, Freiburg, Germany.

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- J.S.E.M. Svensson, C.G. Granqvist, Electrochromic tungsten oxide films for energy efficient windows, *Solar Energy Materials* 11, Issues 1-2, (1984) 29–34.
- K. Van Den Wymelenberg, Patterns of occupant interaction with window blinds: A literature review, *Energy and Buildings* 51 (2012) 165–176.
- M. Zinzi, Office worker preferences of electrochromic windows: a pilot study, *Building and Environment* 41 (2006) 1262-1273.