CAPTURING THE USER EXPERIENCE OF ELECTROCHROMIC GLAZING IN AN OPEN PLAN OFFICE

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Abstract

Electrochromic (EC) glazing shows promise as a viable alternative to fixed transmittance glazing with traditional shading devices. A case study is underway that will examine the retrofit application of EC glazing in a typical office. Whilst this technology has been commercially available since 2003, this is the first installation of its kind in the UK. The study involves the long-term monitoring of physical parameters in the space, as well a repeated measures assessment of the subjective experience of the office workers.

This paper provides an outline of the case study, and will focus on the challenge of capturing the experience of the users.

1 Introduction

In an electrochromic (EC) window, users can control glare from direct sun or bright patches of sky by adjusting the transmittance (or ‘tint’) of the glazing. As EC window technology has advanced, the minimum visible transmittance achievable has become very small (e.g. 2%), increasing the potential of this type of glazing to reduce or even remove dependence on blinds for shading. This could significantly improve the level of access to daylight and views to outside. Furthermore, EC glazing could reduce energy usage through a reduction of electric lighting demand and a reduction of solar heat gain.

The potential of EC glazing is particularly significant when applied to contemporary office buildings with highly glazed facades. Often, these buildings suffer from problems of visual discomfort and solar gain. This in turn can lead to poor daylighting since the blinds are regularly left closed for extended periods (Van Den Wymelenberg, 2012).

2 Background

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 et al 1984). EC glazing began to be characterised as a “smart window” technology, along side various other types of chromogenic glass such as thermochromic, photochromic and gasochromic.

The bulk of previous research into the application of EC glazing in buildings has been based on computer simulations (Moeck et al, 1998; Gugliermetti et al, 2005; Fernandes et al 2013, and others). With the advent of prototype EC glazing panels and market-ready EC glazing products, physical model studies began to emerge around the turn of the century. Some studies used part-scale models (Piccolo et al 2009; Piccolo 2010) and full scale test rooms (Lee et al, 2000, Lee et al, 2002; Lee et al, 2006). A small number of studies using full scale test rooms included human participants (Clear et al 2006; Zinzi 2006). More recently, Lee et al (2012) investigated the performance of EC glazing in a conference room in Washington DC, US. However, the transient occupancy patterns of the conference room ruled out a systematic evaluation of user acceptance. Thus there appears to be a paucity of EC performance evaluation in real world settings and over long-term monitoring periods.

3 Case study outline

A case study is currently underway in two neighbouring open plan offices at De Montfort University, Leicester, UK. The rooms are occupied by a total of eight administration staff who are mostly desk-based. The rooms have large southeast facing windows, which have been replaced with double-glazed EC panels manufactured by SAGE Electrochromics Inc. The glazing units have an electrochromic coating on the inner surface of the outer pane of glass that allows the transmittance of the glass to be altered on application of a small voltage. The glass has a maximum visible transmittance of 62% (clear state) and a minimum of 2% (fully tinted state), with two intermediate tint states, at 20% and 6% visible transmittance. Figure 1 shows the interior of the two rooms before and after the EC glazing installation, and Figure 2 shows the exterior façade.

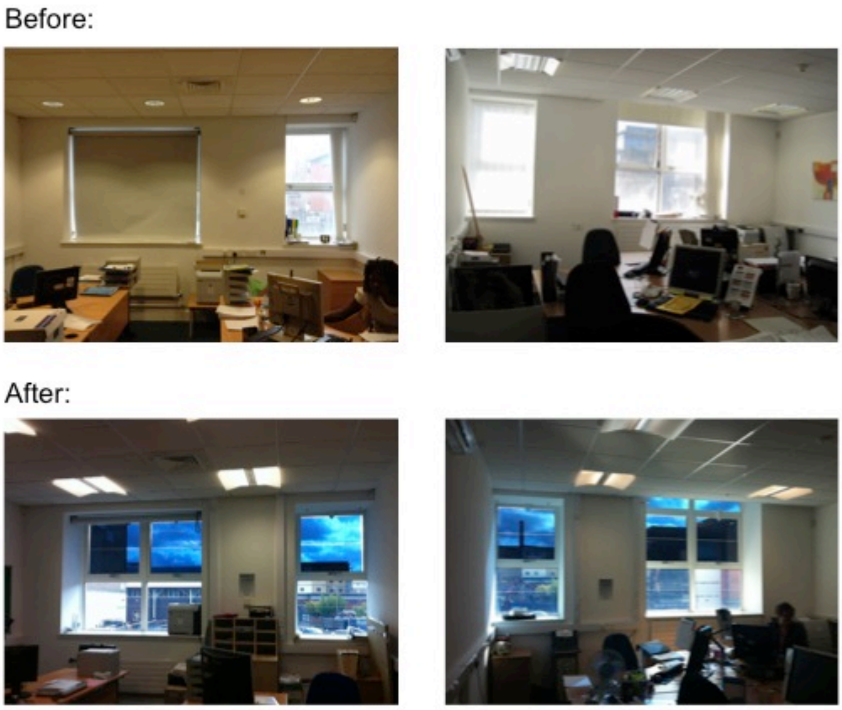


Figure 1 – The interior of the case study offices before and after the EC glazing retrofit

Figure 2 – The exterior façade showing the windows of the two case study rooms

The control system is zoned so that individual panes can be controlled independently. The windows are normally controlled automatically, with wall-mounted switches providing manual control to occupants when desired.

4 Study design

A long-term monitoring campaign began towards the end of 2012. The study will continue for at least 12 months in order facilitate a comprehensive investigation of EC glazing by exploring its performance under the varying in solar conditions throughout the seasons.

The study uses a mixed methods approach, incorporating quantitative measurements of the physical environment, and a parallel programme of subjective assessment to capture the experiences of the occupants, and in particular the impact of the EC glazing on their visual comfort. The two parallel strands will allow subjective data to be linked with physical data at various points of intersection.

The physical measurements include high dynamic range (HDR) image capture, to record the luminance pattern of the visual field of occupants, as well as logging of workplane illuminance, external illuminance at the facade and local weather conditions. In addition, tinting levels and manual overrides for the EC glazing panes are continually logged. Simple Hobo sensors are used to record lighting energy consumption and internal temperatures.

The subjective assessment part of the study is layered, with the aim of collecting data at a useful level of depth and frequency, in order to allow a realistic picture of the users' experience to emerge and to facilitate meaningful analysis. The small number of participants in this study puts an emphasis on the density of observation. The main challenge of the study design is to achieve a balance between minimising participant burden on one hand, whilst capturing good quality information at regular enough intervals (Krosnick, 1999). A combination of approaches is applied to address that:

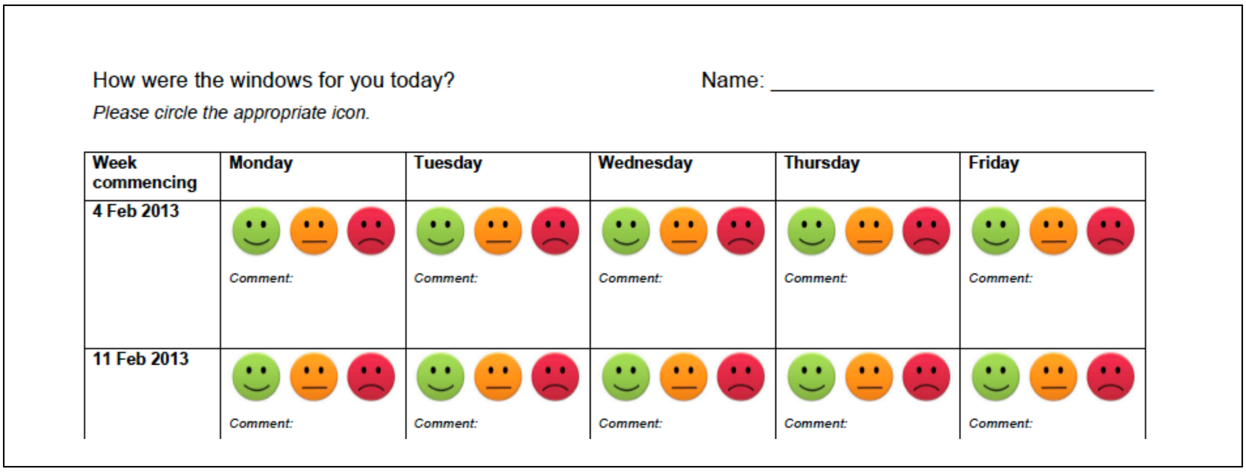
- Daily experience form - This allows participants to record their experience in very general terms, using a traffic light system; "good", "bad" or "neutral".
- Online questionnaire (every two weeks) - This goes into more detail about different aspects of the experience, for example in terms of visual comfort and glare.
- Interview (every 3-4 months) - The interview is one-to-one semi-structured and allows deeper exploration of the subjective narrative.
- Ad-hoc feedback (opportunistic) - Capture of comments made by the room occupants, recorded by the researchers during informal visits to the rooms.

The need to minimise participant fatigue is particularly important in this study due to the small number of participants and the risk to the study should a participant decide to opt out. The different components for the layered capture of subjective data are further explained in the following sections.

4.1 Daily experience sheet

This technique was developed in order to allow regular data capture at a short time interval. Due to risk of participant fatigue in such a long-term field study it was impracticable to administer questionnaires or interviews at high frequency. However, it was felt that collection of subjective data at a daily interval was necessary in order to be able to investigate the links between daily solar conditions and perception of the glazing's performance.

The daily experience sheet contains a table similar to a monthly calendar sheet on which participants can mark their general 'happiness' with the EC glazing performance at the end of each day (see Figure 3). Although recorded at a high frequency, this approach is minimally intrusive, as participants can simply tick the relevant symbol before the leave the office. There is also a space for comments, which participants regularly use to convey additional detail.



How were the windows for you today? Name: ______________________________

Please circle the appropriate icon.

Week commencing	Monday	Tuesday	Wednesday	Thursday	Friday
4 Feb 2013	Comment:	Comment:	Comment:	Comment:	Comment:
11 Feb 2013	Comment:	Comment:	Comment:	Comment:	Comment:

Figure 3 – An excerpt from a daily experience sheet (one sheet per month)

Although the data gathered with this method is rather coarse, it is intended to facilitate an exploration of whether general occupant perception can be linked to average meteorological conditions and/or sun angles (i.e. seasonal variability) and thus give an indication as to how EC glazing performance varies depending on weather and season.

4.2 Online questionnaire

The questionnaire has been designed to collect a good level of detail while still being short enough to be completed relatively quickly. This is a more traditional approach that will facilitate a deeper analysis than the daily experience sheet of the links between physical conditions in the room and occupant perception of the glazing performance.

The online questionnaire is sent every two weeks and is designed to capture the effect of the EC glazing on the following subjective parameters:

- Light level (daylight and electric light)
- Distribution of light
- Dominance of daylight and ability to work without electric light
- Glare (eye)
- Glare (screen reflections)
- Self-reported alertness
- Self-reported emotional state
- Clarity of view through window
- Thermal comfort
- Room colours
- Pleasantness of space

The first question asks respondents to report the current status of each window zone in their room, and most of the subsequent questions are asked with respect to the moment of response (i.e. "right now"). This allows the subjective responses at a given time to be linked with external and internal physical conditions at that time. Responses are mostly given in a scaled form, with free text entries possible at the end of each section.

Visual comfort questions are based on Clear et al (2006), Vine et al (1998), Hygge & Lofberg (1999) and Aries et al (2010). Questions about the affect of the EC glazing on perceived colours in the room are based on Arsenault's 2012 study of preferences for static tinted glazing colours (Arsenault, 2012). Questions about the clarity of the view through the window are based on Clear et al (2006). Self-reported alertness is assessed using the Karolinska Sleepiness Scale (Kaida, 2006). A question about the perceived pleasantness of the room was included as an indicator of overall impression, based on Laurentin et al (2000).

The design of the online questionnaire involved compromising on the number and depth of questions in order to ensure that it could be completed within a reasonable time. Canvassing of the participants during the first set of interviews indicated that 10 minutes was about the maximum length of time they were willing to spend completing the questionnaire every two weeks. A larger time interval of three or four weeks with a longer questionnaire was considered, but the interval was felt to be too long for capturing a broad enough range of physical conditions. An assessment of mood states, using PANAS (Crawford, 2004), was considered, but in the end was not included in the questionnaire as it was found that it added significantly to the amount of time required to complete it. Instead, one question about emotional state, based on Osterhaus (2005), was included, in order to capture some sense of the emotional state of the participant.

4.3 Interviews

While interviews are necessarily more time intensive than the first two techniques, they allow capturing further, more detailed, qualitative data that can help put the measurement data from the other levels into context.

One to one interviews are held every 3-4 months. The interviews are semi-structured, with the aim of gaining insights and gathering qualitative information about the experience of the participants. This encompasses the practicalities of the retrofit installation and the user controls, as well as on-going perception of the visual and thermal environment. The areas explored in the interviews are as follows:

- Visual comfort
- Thermal comfort
- User controls and settings
- Glazing colour and the effect on room colours
- Perception of view through window
- Overall satisfaction

The interviews are held in a private room away from the participants' offices. They are audio recorded, and minimal notes are made by the interviewer to encourage a more natural and open dialogue with the participants. The preamble and closing remarks are scripted, and for the main body of the interview, a mindmap is used. This approach has several advantages. Firstly, all questions and sub-questions are on one sheet, thus avoiding the need for the interviewer to 'flick' through several pages to find questions. Secondly, the mindmap encourages a more 'organic' approach, allowing flexibility in the ordering of questions and sub-questions, depending on how each interview unfolds. The wording of the main questions and sub-questions is scripted in order to ensure consistency and to avoid leading or closed questions where possible.

In general, the interview questions are more open versions of those used in the online questionnaire. Questions are asked with respect to the recent past (*e.g.* the last few weeks) or 'in general'. The interviews are used as a tool to explore the same issues as the online questionnaire, but in more depth (see references above). Questions about the user interface and control settings are based on Zinzi (2006).

Additionally, the interviews allow an exploration of issues that cannot be easily related to an instant in time (e.g. user controls, general acceptance/satisfaction), or that may arise during the retrofit process. The interviews are thus more flexible than the questionnaire, which is designed to remain largely unchanged throughout the study.

4.4 Ad-hoc feedback

While the use of first three techniques were designed at the outset of the study to capture occupant perception data that can be linked with physical measurements, it was found that a further source of data was available: During informal visits to the study area, which were crucial to ensure that the EC system was working and to ensure a successful transition to this novel technology, the office occupants were happy to provide ad-hoc feedback about their experience.

This feedback is being captured in a field study journal. The journal is basically a field study log in which all additional detail is recorded, such as changes to the glazing and monitoring installation, modifications to the control settings, but also occupant feedback that was given outside the more formal questionnaires and interviews.

While this ad-hoc occupant feedback has clear limitation in terms of a rigorous analysis, it does provide useful narrative detail that has been used to inform the retrofit process and was found useful in terms of determining the advantages and limitations of the study setup and gauging participant fatigue.

Moreover, the ad-hoc feedback has been utilized in an on-going iterative process, with the aim of keeping the interview questions relevant, *i.e.* making sure additional issues can be explored in the interviews as they arise. Additionally, this data source will be useful for reporting on the retrofit process itself and can thus feed into further studies and similar retrofit applications.

5 Summary

Experience of the progress so far indicates that the study design is successful in many respects: The dialog with the participants is on-going and has helped to resolve a number of issues that were encountered in the first few weeks after the installation. Moreover, this dialog between manufacturers/installers and participants (via the researchers) has helped to optimize the control settings of the system to cater for the office occupants; a process that provides useful empirical findings that can inform further installations of EC glazing in standard working environments.

Also, while the extent to which participants engage with the different layers of the data capture varies, the general trend is that participants are all still contributing to the different data capture approaches, from notes on daily experience sheets and ad-hoc feedback to questionnaires and detailed interviews. The ad-hoc data was found to be vital in order to ensure participant burden is kept low, particularly in terms of adjusting to the new technology, rather than fatigue with the study itself. However, fatigue with the technology could also increase the likelihood of fatigue with the study – and thus poses a constant risk to a study with a small number of participants.

There is also an indication that the study itself has helped participants to better understand the new EC glazing technology. Experience to date has shown that good dialog in the settling-in period has an important role in terms of giving occupants the confidence to 'play' with the technology and use it to their advantage.

Although the data set is by no means complete, early empirical results indicates that EC glazing has a number of benefits that are valued by users, particularly in terms of daylight provision and connection with the outside. The layered data capture approach is designed to provide a comprehensive data set for the purpose quantifying and qualifying those early indications.

6 Conclusions

EC glazing has significant potential to transform the way we use glass in architecture. The case study described here explores that potential by assessing the impact of the technology on end users in a real world setting. By measuring the subjective as well as the non-subjective effects in a typical office setting under normal use, a valuable data set is expected.

This paper explores the challenges of real world research, in particular with regards to balancing the need for frequent data collection with limiting participant burden. A data collection approach is described that has been designed for, and is applied to, a long-term study of EC glazing performance in an office setting. The study is on-going, with participant engagement remaining high, which indicates that the study design has been successful in moderating the effect of continuous observation on participant fatigue.

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References

ARIES, M.B.C., VEITCH, J. A., NEWSHAM, G. R. 2010. Windows, view, and office characteristics predict physical and psychological discomfort. Journal of Environmental Psychology, 30(4), 533–541.

ARSENAULT, H., HEBERT, M., DUBOIS, M-C. 2012. Effects of glazing colour type on perception of daylight quality, arousal, and switch-on patterns of electric light in office rooms. Building and Environment, 56, 223–231.

CLEAR, R.D., INKAROJRIT, V., LEE, E.S. 2006. Subject responses to electrochromic windows, Energy and Buildings 38, 758–779.

CRAWFORD, J.R., HENRY, J.D. 2004. The Positive and Negative Affect Schedule (PANAS): Construct validity, measurement properties and normative data in a large non-clinical sample. British Journal of Clinical Psychology, 43(3), 245-265.

FERNANDES, L.L., LEE, E.S., WARD, G. 2013. Lighting energy savings potential of split-pane electrochromic windows controlled for daylighting with visual comfort, Energy and Buildings, In Press – Accepted Manuscript.

GUGLIERMETTI, F., BISEGNA, F. 2003. Visual and energy management of electrochromic windows in Mediterranean climate, Building and Environment 38, 479 – 492.

GUGLIERMETTI, F., BISEGNA, F. 2005. A model study of light control systems operating with Electrochromic Windows, Lighting Research & Technology 37, 3-20.

HYGGE, S., LOFBERG, H.A. 1999. Post occupancy evaluation of daylight in buildings - IEA SHC Task 21. Technical report, KTH - Royal Institute of Technology, Sweden.

KAIDA, K.,TAKAHASHI, M., AKERSTEDT, T., NAKATA, A., OTSUKA, Y., HARATANI, T., FUKASAWA, K. 2006. Validation of the karolinska sleepiness scale against performance and eeg variables. Clinical Neurophysiology, 117(7), 1574–1581.

KARLSSON, J., KARLSSON, B., ROOS, A. 2000. Control strategies and energy saving potentials for variable transmittance windows versus static windows, Proceedings of Eurosun, Copenhagen, Denmark.

KARLSSON, J. 2001. Control system and energy saving potential for switchable windows, Proceedings of Seventh International IBPSA Conference, Rio de Janeiro, Brazil.

KROSNICK, J. 1999. Survey research. Annual review of psychology, 50, 537–567.

LAMPERT, C.M. 1984. Electrochromic materials and devices for energy efficient windows, Solar Energy Materials 11, 1–27.

LAURENTIN, C., BERMTTO, V., FONTOYNONT, M. 2000. Effect of thermal conditions and light source type on visual comfort appraisal. Lighting Research and Technology, 32(4), 223–233.

LEE, E.S., DIBARTOLOMEO, D., SELKOWITZ, S. 2000. Electrochromic windows for commercial buildings - Monitored results for a full-scale testbed, Report Number: LBNL-45415 DA-414. Technical report, Lawrence Berkeley National Laboratory.

LEE, E.S., DIBARTOLOMEO, D. 2002. Application issues for large-area electrochromic windows in commercial buildings, Solar Energy Materials & Solar Cells 71, 465–491.

LEE, E.S., DIBARTOLOMEO, D., SELKOWITZ, S. 2006. Daylighting control performance of a thin-film ceramic electrochromic window: Field study results, Energy and Buildings 38, 30–44.

MOECK, M., LEE, E.S., RUBIN, M.D., SULLIVAN, R.T., SELKOWITZ, S.E. 1998. Visual quality assessment of electrochromic and conventional glazings, Solar Energy Materials and Solar Cells 54, 157-164.

OSTERHAUS, W. K. E. 2005. Discomfort glare assessment and prevention for daylight applications in office environments. Solar Energy, 79(2),140–158.

PICCOLO, A. 2010. Thermal performance of an electrochromic smart window tested in an environmental test cell, Energy and Buildings 42, 1409–1417.

PICCOLO, A., PENNISI, A., Simone, F. 2009. Daylighting performance of an electrochromic window in a small scale test-cell, Solar Energy 83, 832–844.

PICCOLO, A., SIMONE, F. 2009. Effect of switchable glazing on discomfort glare from windows, Building and Environment 44, 1171–1180.

SVENSSON, J.S.E.M., GRANQVIST, C.G. 1984. Electrochromic tungsten oxide films for energy efficient windows, Solar Energy Materials 11, 29–34.

VAN DEN WYMELENBERG, K. 2012. Patterns of occupant interaction with window blinds: A literature review. Energy and Buildings, 51(0), 165–176.

VINE, E., LEE, E.S., CLEAR, R.D., DIBARTOLOMEO, D., SELKOWITZ, S. 1998. Office worker response to an automated venetian blind and electric lighting system: a pilot study. Energy and Buildings, 28(2), 205–218.

ZINZI, M. 2006. Office worker preferences of electrochromic windows: a pilot study, Building and Environment 41, 1262–1273.