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Control criteria of electrochromic glasses for energy savings in mediterranean buildings refurbishment

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Abstract

During the next decades the refurbishment of old buildings will be an essential way to contribute to the global improvement of buildings energy performance indicators. Within this context, the present paper is focused on the use of electrochromic (EC) windows, an emerging technology alternative to shading devices, to control solar gains in buildings located in Mediterranean climates. The optical properties adjustments of the EC glasses are discussed based on the incident solar radiation. The ESP-r building energy simulation software was used to study the energy savings resulting from the application of electrochromic windows, considering the comparison of several windows solutions (single, double-glazing and EC windows) and windows orientations (East, South and West). In addition, different transition ranges for the optical properties of the EC glasses are assessed through the analysis of the energy needs for space heating and cooling. The main conclusion is that EC technology is an effective option in cooling dominated buildings. The impact of EC windows is highly dependent on facade orientation, being a valid option particularly in the cases of the East and West facades. For these facades, the control set point found to be effective corresponds to an incident solar radiation on the glass of 150 W/m^2 to impose a total coloured state. For the South facade the results show no significant advantage of using EC windows.

Keywords: Building refurbishment; Solar gain control; Electrochromic windows; Building energy performance simulation

1. Introduction

Windows and glazed surfaces are the elements of the buildings envelope that require more attention at design, specification and operation, since the control of both thermal losses in the heating season and solar heat gains in the cooling season are crucial for the thermal behaviour of buildings. It is not an easy task to settle the dimensions of the glazed areas in such a way as to balance the energy consumption of the heating, ventilation and air conditioning (HVAC) systems and the use of daylight to minimize energy use for artificial lighting, simultaneously providing high visual comfort (Ochoa et al., 2012). Moreover, labour productivity is higher in the presence of daylight and the possibility of seeing the exterior surroundings (Ochoa et al., 2012). Keeping this in mind, several studies using building energy dynamic simulation have been performed to assess the energy impact of using more efficient glazing systems (Freire et al., 2011), the general conclusion being that the replacement of existing single glazing windows

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by double glazing windows appears to be an effective solution (Rahman et al., 2010).

To address such problems, new window solutions have been developed (Gil-Lopez and Gimenez-Molina, 2013; Gao et al., 2014) and the performances of different kinds of shading devices were also studied in different climatic conditions and facade orientations (Palmero-Marrero and Oliveira, 2010; Huang et al., 2014). The intelligent control of shading devices and openings in order to optimize comfort and minimize energy demand was recently studied in Denmark (Liu et al., 2015).

This paper presents a study aiming at answering the following research question: what is the most suited control strategy to apply to electrochromic (EC) glasses and what is the influence that internal loads may have on their operation in the Mediterranean climate, taking into account the influence of the facade orientation? The obtained results may contribute to the future automation of such electrochromic devices, that can be controlled by Building Automation and Control Systems (BACS) (Marinakis et al., 2013), using the information gathered from solar radiation sensors located on the facades.

Some of the works analysed present a comparison between static and dynamic glazing solutions (Hee et al., 2015) in several climates (DeForest et al., 2013). These comparisons have frequently been made through the use of simulators (DeForest et al., 2013) and/or based in previous works (Hee et al., 2015). Some works tried to validate the simulated results by comparison with experimental data (Jelle, 2013), having as main goal to explain the dynamics of the EC glass, its properties and how it behaves (Jelle, 2012, 2013). The works of Lee et al. (2012) and Kelly et al. (2013) present a pilot building retrofitting replacing single glass with double EC glass from SAGE™. In this open space office case study some measurements were made. Jelle (2012) shows how EC glass can be used in building refurbishment and presents a complete review of dynamic glass solutions (special glasses). These works show that glazing with controllable properties is a suitable technology for energy control in buildings and aims at overcoming the challenges mentioned for conventional glazing, still with similar functionality and properties.

Aldawoud (2013) makes an analysis based on simulation of solar gains in space zones at the East, South and West facades, comparing conventional shading systems with EC glasses in hot and dry climates.

EC glasses need a control strategy to manage when they should be in the coloured or in the clear state (Roos et al., 2005a). This strategy can be based on several parameters, one of which is occupant's preference, which is unpredictable. Minimizing energy consumption is not necessarily the occupants' main goal. Reducing reflections and/or glare could be the major factor for those working on computers, while interior temperature could be the most important for other occupants (Selkowitz and Lee, 2004; Lee et al., 2006). The physical or time-related parameters that can be used to control EC glasses are, according to Roos et al. (2005a), solar irradiation, external temperature, indoor temperature, indoor light level, occupation profile, time of the day and season. Different adjustments and control algorithms correspond to each one of these parameters. Moreover, the system should have a response in such a way that it does not react to short duration changes, such as a cloud covering the sun for a short period of time. As the switching time is several minutes, a high time constant should be used to control the EC glass, in order to avoid frequent changes (Roos et al., 2005a).

One of the goals of Fernandes et al. (2013) in the control of the EC glass is to maximize thermal comfort and the use of daylighting, without concern on reducing energy consumption. Sbar et al. (2012) simulates EC glasses (data from SAGE™) in East, South and West facades, in different climates, with the goal of maximizing daylighting and minimizing electrical energy consumption for lighting.

Some works just use value of the solar incident radiation to control EC glasses, which is a reductionist approach (Sullivan et al., 1994, 1996; Karlsson, 2001; Gugliermetti et al., 2002; Tavil and Lee, 2005; Assimakopoulos et al., 2007; Jonsson and Roos, 2010).

It is of interest for this study that the transition time depends on the EC glass area (Rottmann et al., 2005), materials and temperature (Lee et al., 2000; Lee and DiBartolomeo, 2002; Bell et al., 2002). It is possible to keep the device at any of the intermediate states. For a 10 cm × 30 cm glass, 300 s are necessary for full colouring or bleaching (Rottmann et al., 2005); for a 1.2 m × 0.8 m size electrochromic element, 20 min is needed for one complete switching cycle (colouring and bleaching). The colouring step takes 12 min and the bleaching step takes 8 min (Kraft and Rottmann, 2009). EC glasses could have two main states: completely coloured and completely clear. According to Rowley and Mortimer (2002), Argun et al. (2004) and Jelle (2012, 2013), different colours are possible (blue, yellow, green, red, grey, etc.) allowing architects to create diverse external building appearances. Furthermore, Argun et al. (2004) stated that an EC glass composed of conjugated polymers is the most suitable to change its structure creating different colours. When a material can have more than two electrochemical states, it can present several different colours, being designated poli-electrochromic (Rowley and Mortimer, 2002). Despite some of these colour possibilities being still under development, some manufacturers have already some commercial solutions available, such as E-Control® GmbH & Co. KG (EControl, n/a), Gesimat GmbH (Gesimat, 2012) and SAGE™ Electrochromics, Inc. (SAGE, n/a) with colours varying from "transparent" (clear) to blue (coloured).

The lifetime of this technology is currently estimated to be 20–30 years. The tests are made with millions of cycles. The most common is to consider 5 cycles per day. Companies such as SAGE™ Electrochromics, Inc. (SAGE, n/a), E-Control® GmbH & Co. KG (EControl, n/a) and Gesimat GmbH (Gesimat, 2012) warrant their EC glasses for 10 years (Baetens et al., 2010; Ritchie,