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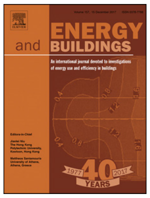

Energy performance of an electrochromic switchable glazing: Experimental and computational assessments

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ABSTRACT

This paper describes the results of experimental tests and computer simulation modelling aimed at evaluating the performance of an electrochromic (EC) window with respect to solar radiation control and the relative impact on the energy consumption of buildings of the residential type for two typical Italian climates. The research is carried out by a test-cell equipped with a small area EC double glazing unit and by a simulation program of buildings' energy behaviour in transient regime. The experimental results show that EC devices which modulate solar radiation mainly by absorption, like the one investigated in this paper, generate secondary solar heat gains which entails a 20% decrease of the maximum potential energy flux reduction. Also, this effect could rise the temperature of the internal glass pane of the glazing to levels for which risk of thermal discomfort for the occupants may occur. The computer simulation modelling involves a residential building unoccupied during a large fraction of daytime in weekdays. The savings potential of the investigated EC window are calculated relative to a conventional clear float double glazing unit. Results show that the EC glazing may lead to a considerable decrease of the cooling energy demand (and of the total building energy consumption) in cooling dominated climates. The energy saving benefits become less marked in heating dominated climates and, for low values of the window-to-wall ratio, can be overcame by the increase in lighting and heating energy requirements that results in an increase of the total building energy demand.

1. Introduction

Smart windows based on electrochromic (EC) technology are currently one of the major research topics in the field of advanced buildings' glazing. These devices are able to regulate the amount of radiant energy that flows inside the buildings through the windows by changing reversibly their optical transmittance under the action of a low electrical voltage [1]. The application of this new class of switchable glazing should result in a reduction of the use of mechanical air conditioning systems, especially in cooling dominated climates, with considerable benefits in terms of energy saving. In addition, they should allow effective control of the levels of daylight and glare for visual comfort management.

Intensive research has been conducted by either full-scale [2–8] and small-scale test cells [9–11] or numerical simulations [12–29] to investigate the effect of EC switchable glazing on buildings' energy performance and indoor visual/thermal comfort conditions. The results of almost all these studies converge on the conclusion that EC windows may constitute an effective energy saving technology in cooling dominated locations and, also, a powerful daylighting control technology for improving indoor visual comfort.

Although the above research spans a wide range of, geographic, building envelope, climate and operating conditions there are still some poorly investigated issues, strictly related to the energy performance potential of these devices, that could draw the attention of researchers.

The first issue is concerned with the assessment of the modulation operated by the EC switchable glazing on the incoming radiant energy flux. This task entails the accurate quantification of the energy flux components released to the indoor environment by an EC glazing when exposed to the solar radiation. It must be observed, in fact, that for conventional WO_3 based EC devices the change in optical transmittance in response to the applied voltage is light absorption so only a small fraction of the impinging solar radiation is reflected off. This entails that the internal surface of a single-pane EC window–when switched to low transmittance

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states–releases a great fraction of the absorbed radiation towards the indoor environment via convective and radiative heat transfer. This secondary heat flux may evidently lead to a decrease of the performance of the device in operating as a shading device and to a risk of thermal discomfort originating from radiative exchange between a hot window and the occupants. Furthermore, unwanted damage of the EC layer may occur if the glazing gets much too hot. Investigation on this topic was performed by Klems [2] who measured the heat flows and temperatures affecting the operation of a skylight formed by a low-e double glazed unit (DGU) comprising an EC layer on surface 2. Measurements, made on summer time, showed that in its fully coloured state the EC DGU achieved temperatures as high as 50 and 70 °C in the inner (surface 4) and outer (surface 1) glass surfaces respectively. Lee and Di Bartolomeo [3] determined by numerical computations the surface temperatures of a fully coloured EC DGU window and concluded that the inside surface glass temperature should not significantly contribute to thermal discomfort. Fang and Eames [30] simulated by a 3-D finite volume model the thermal behaviour of a three-pane EC vacuum glazing and deduced that the glass pane with the EC layer must face the outdoor environment to prevent the glazing from getting high (damaging) temperatures. Furthermore, a low-e coating [31,32] could improve the glazing thermal performance as also concluded by Lim et al. [33] and by Jonsson and Ross [20].

The second issue is concerned with the circumstance that most of the computational investigations performed so far considered the impact of EC glazing on the energy consumption of commercial buildings and offices. Only very few simulation studies have analysed the performance of EC windows in residential buildings, although this specific investigation could be worthy of attention since the performance of a shading device is generally influenced, among other factors, by the building's use. Residential buildings were considered in their research by Pal et al. [27] who found that in a townhouse building located at high latitudes (Helsinki) the application of EC windows doesn't bring any energy benefits compared to conventional and other advanced windows. Conversely, Yik and Bojic [16] found that in high-rise residential buildings located at low latitudes (Hong Kong) the application of switchable glazing would lead to a reduction in the annual electricity consumption for space cooling by up to 6.6%. Jonsson and Ross [20] investigated the effect of EC DGU windows (with and without antireflective coatings) for a wide range of climates in residential buildings and found that conventional uncoated DGU windows are outperformed by the switchable glazing both for the heating and cooling seasons. More recently, De Forest et al. [29] calculated the annual primary energy saving (normalized by window area) deriving from the application of different advanced EC DGU windows in midrise residential buildings relative to the local ASHRARE-compliant window. The energy saving resulted about 130 kWh/m^2-year for a cooling dominated climate (Huston) and over 160 kWh/m^2-year for a heating dominated climate (Chicago).

The present work try to address the two above discussed issues by both experimental and computational capabilities. The experimental investigation is performed under real weather conditions and involves the use of a small-scale test cell equipped with a small area EC device and instrumented with a number of sensor for quantifying the energy flux entering the test cell through the EC glazing. The computational investigation involves the use of a simulation software of building behavior in dynamic regime for studying the potential of EC windows to reduce energy consumption in a residential building for two typical Italian climates. The results of the present study may constitute useful information for assessing the potential of these devices in reducing buildings' energy consumption when integrated in real building facades.

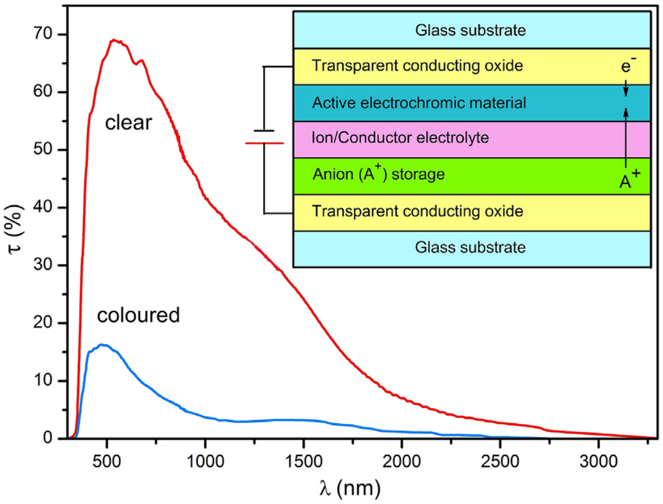

Fig. 1. Optical transmittance spectra of the EC device in the full bleaching (red line) and full colouring (blue line) states. In the insert the multilayer structure of the EC device is shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Climatic parameters of the selected towns.

	Bolzano	Messina
Min yearly temperature (°C)	−11.6	5.0
Max yearly temperature (°C)	34.6	34.9
Heating degree-days (°C gg)	2913	758
Cooling degree-days (°C gg)	254	1085
Climate [37]	Moist continental	Mediterranean

2. Methodology

The EC glazing considered in this study is a home-made fully solid state EC device. It is based on the complementary electrochromism of WO_3 (the "active" layer) and NiOH:Li (the "ion storage" material) electrically interacting through a Li^+ ion conducting polymer (PEO-PEGMA:Li). The layers are deposited on two glass substrates covered by fluorine doped tin oxide ("K glass" [34]) according to the scheme illustrated in Fig. 1. A sample of area 12 × 12 cm^2 switches reversibly from a transparent state to a dark blue with a low value of applied potential ± 2.5 V. The typical switching time for the colouring process, is about 5–6 min (from about 70 to 30% visible transmittance) while the bleaching process takes a shorter time. Considerable lower transmittances (∼7%) are attainable anyway by switching the device for longer times but at expense of its reversibility behaviour. In Fig. 1 The UV-VIS-NIR (near) normal transmittance spectra, measured by a Perkin-Elmer Lamda 2 spectrophotometer in the 300–1000 nm range and by a Perkin–Elmer system 2000 FT-IR in the 1000–3500 nm range is illustrated for the fully bleached and fully coloured states.

Additional information on the optical, electrical and dynamic behaviour of the device can be found in [35,36].

The thermal performance of this device is investigated by both experimental and computational capabilities in two Italian locations characterized by different climatic conditions. The first selected centre, Messina (latitude: 38° 12′, elevation: 51 m), exhibits a typical Mediterranean climate, with cooling periods prevalent with respect to heating ones. The second selected centre, Bolzano (latitude: 46° 28′, elevation: 241 m), is characterized by a moist continental climate typical of Alps and Apennines, with cold winters and marked yearly thermal excursions. The climatic parameters of the selected towns as reported in Table 1.

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