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Visual and energy performance of switchable windows with antireflection coatings

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Abstract

The aim of this project was to investigate how the visual appearance and energy performance of switchable or smart windows can be improved by using antireflective coatings. For this study clear float glass, low-e glass and electrochromic glass were treated with antireflection (AR) coatings. Such a coating considerably increases the transmittance of solar radiation in general and the visible transmittance in particular. For switchable glazing based on absorptive electrochromic layers in their dark state it is necessary to use a low-emissivity coating on the inner pane of a double glazed window in order to reject the absorbed heat. In principle all surfaces can be coated with AR coatings, and it was shown that a thin AR coating on the low-e surface neither influences the thermal emissivity nor the *U*-value of the glazing. The study showed that the use of AR coatings in switchable glazing significantly increases the light transmittance in the transparent state. It is believed that this is important for a high level of user acceptance of such windows.

Keywords: Antireflective coatings; Smart windows; Energy simulations; Optical simulations

1. Introduction

Future energy saving requirements in combination with increased comfort are expected to lead to a demand for glazing which can vary their transmittance to reduce the heating need during cold periods and reduce the cooling need during warmer periods (Selkowitz and Lee, 2005; Platzer et al., 2005). However, such switchable or smart windows tend to have significantly lower light transmittance than a regular window even in the transparent state, which could lead to a lower user acceptance. Thus it is of interest to evaluate the influence of using antireflective (AR) coatings in such windows in order to improve their light transmittance.

Antireflective coatings can be deposited using different techniques. Sputtering is regularly used for multilayer coatings optimised for the visible wavelength range (Schubert et al., 2008) and the less expensive dip-coating technique can be used for single layer coatings with a broadband antireflection effect. With this method the samples are dipped in a sol with silica spheres of controlled sizes, a sol–gel (Nostell et al., 1998). Etching of the glass surface in hydrofluoric acids also produce antireflection layers (Minot, 1976; Chinyama et al., 1993; McCollister and Pettit, 1983) and surface micropatterning of plastic surfaces leads to an antireflection effect for plastic surfaces (Gombert et al., 1998; Gombert et al., 2000). The AR coated samples in this study have been prepared using the dip-coating technique, resulting in a porous layer of SiO_2 spheres, which was assumed to have an effective refractive index of around 1.31 (Nostell et al., 1999).

The samples used in this study were ordinary float glass, hard-coated low-e glass and an electrochromic device deposited on and laminated in a plastic film (Granqvist, 1995; Azens et al., 2005). The increased transmittance leads to higher solar and light transmittance, while not affecting

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the *U*-value of the glazing. Electrochromic glazing with and without antireflective coatings were simulated, compared and evaluated. Previous studies have shown that the light transmittance and the direct solar transmittance can increase by up to 7% and 4% points, respectively, for regular float glass (Hammarberg and Roos, 2003). The energy performance of smart windows has been studied within the International Energy Agency, Solar Heating and Cooling Programme, Task 27. The results indicate considerable energy savings and in particular that the cooling need in moderately warm climates can be almost eliminated (Roos et al., 2005). The effect on energy consumption for artificial lighting when using switchable glazing has been studied within the "SWIFT" project (Platzer, 2003).

This study has focussed on a double glazed window design with an electrochromic pane as the outer pane and a low-e coated glass as the inner pane. The low-e pane was chosen as a tin oxide based hard-coating. The electrochromic pane can consist of two glass panes with the electrochromic layers laminated in between, see Fig. 1. Another possible design is to use an electrochromic plastic film laminated onto the inner or outer surface of the outer pane. For protection against weathering the position on the inner side is preferred. A major reason for using the film is the huge retrofitting market for this kind of window, where existing window frames can be used, the electrochromic film can be laminated onto the outer pane and the inner pane can be replaced by a hard-coated low-e pane.

2. Method

The transmittance and reflectance spectra for the glazing were calculated using Fresnel formalism as described in Pfrommer et al. (1995) in combination with experimental spectra. For the electrochromic layers, refractive indices were taken from the Windows and Daylighting Group at the Lawrence Berkeley National Laboratory (Windows Daylighting Group – Lawrence Berkeley National Laboratory, 2009). Experimental spectra for the low-e pane were used, while for the electrochromic layers calculated values were used. This was because data for the electrochromic coatings are not officially available. The spectra used for the dark and the clear states are, however, reasonable and readily possible to achieve. The exact values of the transmittance in the two states are not crucial for the objectives of the investigation and the chosen spectra show the trends in a clear way.

The simulation tool Winsel was used to estimate the energy balance of these smart windows when placed in a building. Winsel is a tool for estimating how different windows affect the energy balance of a building. It can thus give accurate values of the energy saving potential for the heating and cooling of a building depending on which window glazing is used. As input, the program uses climate data such as outdoor temperature, direct and diffuse solar radiation and a limited number of building parameters (Karlsson et al., 2001). The program calculates the energy losses due to the *U*-value together with the solar gain depending on the *g*-value. The effect on artificial lighting has not been included in the calculations.

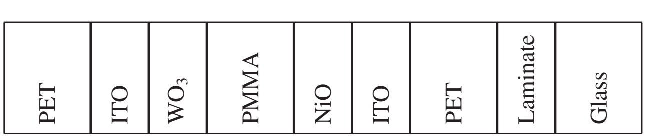

Fig. 1. Schematic drawing of the different layers in the electrochromic film, not to scale.

For the energy calculations in this study, an office building with a balance temperature of 8 °C and a residential building with a balance temperature of 12 °C were assumed. Three locations were simulated; Stockholm, Denver and Miami, and weather data were taken from the software tool Meteonorm (Meteotest, 2003). The locations were selected to cover a wide range of climates; hot with no real winter in Miami, hot summers and cold winters in Denver and moderate winters and summers in Stockholm.

For the simulations of the switchable glazing, control strategies based on user presence were assumed for both buildings. The control strategy for the residential building assumes that someone is present for one hour in the morning and for half of the time during 4 pm and 11 pm. The office control strategy assumes that someone is present for half of the time during 7 am and 4 pm. When somebody is present, the control system sets the window in a state determined by the solar irradiation. The threshold for the solar irradiation was defined as when the perpendicular component of the transmitted direct solar radiation was 200 W/m^2.

As soon as nobody is present the control system sets the window in an energy optimisation state. "Energy optimisation" means that the windows are always kept in the state that is best from a heating and cooling perspective, while neglecting the energy used for electric lighting. In the simulations the windows are kept in a low-transparent state whenever there is a need for cooling and in a high-transparent state whenever there is a need for heating. It is assumed that heating is needed whenever the outdoor temperature is below the balance temperature of the building, which is 8 °C and 12 °C for the residential and office building, respectively. Cooling is assumed needed when the outdoor temperature is 5 °C higher. Simulation modes corresponding to the different control strategies are presented in more detail elsewhere (Jonsson and Roos, 2010).

Five different double glazed window configurations were simulated according to Table 1. The switchable window combination with the low-e coating is depicted in Fig. 2. The picture shows the version with an electrochromic film laminated onto the outer window pane. An all-glass electrochromic device could also be used with identical optical properties.

3. Results

The simulation results show that the decrease in reflectance due to the use of antireflective coatings in electrochro-