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Evaluation of control strategies for different smart window combinations using computer simulations

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Abstract

Several studies have shown that the use of switchable windows could lower the energy consumption of buildings. Since the main function of windows is to provide daylight and visual contact with the external world, high visible transmittance is needed. From an energy perspective it is always best to have the windows in their low-transparent state whenever there are cooling needs, but this is generally not preferable from a daylight and visual contact point of view. Therefore a control system, which can be based on user presence, is needed in connection with switchable windows. In this study the heating and cooling needs of the building, using different control mechanisms were evaluated. This was done for different locations and for different combinations of switchable windows, using electrochromic glazing in combination with either low-e or solar control glazing. Four control mechanisms were investigated; one that only optimizes the window to lower the need for heating and cooling, one that assumes that the office is in use during the daytime, one based on user presence and one limiting the perpendicular component of the incident solar irradiation to avoid glare and too strong daylight. The control mechanisms were compared using computer simulations. A simplified approach based on the balance temperature concept was used instead of performing complete building simulations. The results show that an occupancy-based control system is clearly beneficial and also that the best way to combine the panes in the switchable window differs depending on the balance temperature of the building and on the climate. It is also shown that it can be beneficial to have different window combinations for different orientations.

Keywords: Smart windows; Energy simulations; Control strategies; User presence; Solar energy; Building simulations

1. Introduction

The use of fossil fuels passed biomass as the main energy source at the end of the 19th century and has been steadily increasing since then. This is not a sustainable condition and the fact that there is a limited supply of oil, coal and natural gas in the world (Aleklett and Campbell, 2003); together with the recent global warming issue, makes it necessary to completely reconsider our present energy consumption habits. The building sector offers the largest potential for improved energy efficiency in Europe and 30–40% of all primary energy in the world is used for buildings. Windows are the least insulating part of the thermal envelope and therefore a key component for achieving reduced energy consumption in buildings (United Nations Environment Programme, 2007).

A proper choice of windows can help to reduce both heating and cooling needs by reducing heat losses and solar heat gains through the windows. Depending on continuously varying climate conditions, the windows should preferably have a high solar heat gain when there is a need for heating and a low solar heat gain when there is a need for cooling. This can be achieved by external shading such as awnings, but such a solution might have drawbacks, for example sensitive mechanical parts, reduced outside view and outside aesthetics and mounting problems. Thus the emerging technology for switchable, usually electrochro-

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mic, windows provides an obvious opportunity to save energy in buildings. The purpose of a window is not only to let in light and create visual contact with the surroundings, but also to give a comfortable indoor climate and to minimize energy use.

The link between low energy use and good visual and thermal comfort is therefore a control system, where the windows are optimized for personal comfort when someone is present and for low energy use when nobody is present. When someone is present in a room the windows should be light enough to give a comfortable light level in the room, while still avoiding annoying glare. Whenever the room is unoccupied the window can be low-transparent if there is a need for cooling and high-transparent if there is a need for heating. Unfortunately the two requirements of energy optimization and occupancy comfort are not always in agreement. It is therefore also important to acknowledge that any control system should always have an override switch for privacy and individual comfort of the occupants.

The dominating switchable technology today is based on electrochromic coatings where a low voltage is applied between two transparent conductors with intermediate layers that switch between a low-transparent absorbing state and a high-transparent state upon injection or rejection of charged ions into the active electrochromic coatings (Granqvist, 1995). The mechanism is similar to that of a rechargeable battery.

The electrochromic layers can be laminated between two glass panes, laminated between two plastic flexible foils or coated on one of the glass surfaces. All three technologies are in principle related and they have their advantages and disadvantages, depending on the application strategy. With the current trend of energy conservation, it is far from sufficient to introduce efficient technologies in new buildings, it is also absolutely necessary to drastically reduce the energy consumption in older buildings. In this respect the flexible foil technology has an advantage as it can be introduced in existing windows without replacing any of the window frames.

Several simulation studies on smart windows have been performed earlier with various approaches. See for example Lee and Tavil (2007), Assimakopoulos et al. (2004) or Karlsson (2001). The aim of this study was to investigate to what extent different control strategies that were developed for a window energy balance simulation tool, Winsel, can be used to evaluate different window combinations and to see how the different control strategies affect the energy use (Karlsson et al., 2001). This was achieved by investigating how a control system can be configured and how this affects the energy balance of the window under different assumptions, and also by investigating how different window combinations perform together with the different control strategies in various climates and for different orientations.

2. Method

The optical properties of the windows were calculated using a combination of the Fresnel formalism and experimental data. The international standards International Organization for Standardization (2003) and European Comittee for Standardization (1998) were used to calculate the solar factor (g-value) and the thermal conductance (U-value), respectively. For the electrochromic layers, refractive indices were taken from Windows Daylighting Group (2009). The refractive indices were used together with Fresnel formalism to determine the transmittance and reflectance of the complete windows that were "constructed". The choice of electrochromic windows is thus based on simulations, rather than on actual products. This is, however, no limitation since the main objective of the study was to investigate the method and to compare different strategies, not to evaluate the performance of actual products.

The window surfaces are labeled 1–4 from the outer surface to the inner surface according to common practice. Only double paned windows were considered in this study, although in the future it is quite possible to see more of triple glazed windows in high performance low energy buildings. Four double pane reference windows were identified: A window without any coatings, two windows with low-e coatings on surface 3, one with a tin oxide coating and one with a silver based coating, and finally a window with a silver based solar control coating on surface 2.

These reference windows were then combined with electrochromic coatings forming another set of 6 different windows: The uncoated double pane window and the two low-e windows were combined with an electrochromic coating on surface 2. The solar control window was combined with an electrochromic coating on surface 3 and also modified so that the electrochromic coating was on surface 2 and the solar control coating on surface 3. In addition a solar control window with both the electrochromic layer and the solar control layer on the outer pane was designed. The different window combinations are summarized in Table 1 and presented schematically in Fig. 1. All the investigated electrochromic windows can be manufactured with known technologies.

The window simulation tool Winsel was used to estimate the energy balance of these switchable windows, also known as smart windows, when they are installed in a building. The software tool calculates the contribution from the window to the energy balance of the building, without having to know the total consumption of the whole building. It takes solar heat gain into account in combination with thermal losses or thermal gains through the window. For this the program uses outdoor temperature, direct and diffuse solar radiation and calculates energy losses and solar gain using U and g-values, respectively, as input. The building is simulated through its balance temperature and a time constant for heat capacitance. The balance temperature of a building is defined as the outside temperature below which the building needs heating. It depends on the U-value of the building envelope and the internal energy loads. The balance temperature for cooling is in the same way defined as the outside temperature above which the building needs cooling.