ELECTRICALLY CONTROLLED WINDOWS: PERFORMANCE OF NEW PRODUCTS

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ABSTRACT

A new generation of electrically controllable architectural insulating glasses is currently becoming commercially available. The advantages of these smart windows compared to standard glazings are the possibility to control the transmittance of solar radiation and hence the opportunity to avoid additional shading systems.

In order to get detailed information about two new products (SAGE Glass, SAGE Electrochromics inc. and EControl-Glas, EControl-Glas GmbH & Co. KG) we performed a full analysis of the performance by applying our set-up presented in a former CISBAT conference [1, 2]. Our measurements include a full optical characterisation by studying the spectral and angular dependent transmittance and reflectance that yield all relevant one-figure parameters such as solar direct transmittance τ_e, solar direct reflectance ρ_e, solar direct absorptance α_e, light transmittance τ_v, light reflectance ρ_v, and complete colour information of the transmitted and reflected light as well as the general colour rendering index R_a (all parameters as a function of the angle of the incident light). Furthermore, the g-factor has been determined as a function of the incident light by using a solar simulator [2, 3]. All these measurements have been performed for switching steps defined by the manufacturer's control units (two controlling states, bright-dark for the SAGE glass and five discrete states for the EControl glass).

The switching dynamics of smart windows is an important issue and therefore has been analysed by recording transmittance spectra over an extended time period. Furthermore, the consumption of electrical energy for switching and holding a transmittance state has been analysed.

Though we cannot assess the life cycle, the performance of the two product analysed in the present study indicate a clear improvement over former smart windows in several respects.

INTRODUCTION

Overheating of buildings due to extreme heat loads by solar radiation has become a well known phenomenon caused essentially by architectural preferences for highly glazed façades on one hand and by climatic changes on the other hand. Measures to avoid overheating could be appropriate architectural design, variable shading and blinds, sun protection windows, and switchable window glazings. The advantage of switchable windows by using electrochromic phenomena is the dynamic control of solar energy and visible light. Electrochromic windows therefore can contribute to the reduction of the energy needed for cooling and with it increase the comfort of occupants in the building.

For switchable windows two coating types are used, the all-ceramic coatings and coatings containing a polymer foil. In both cases the multilayer stack consists of two transparent conductors, an electrochromic tungsten oxide (WO_3) film, an ion conductor, and a counter electrode. The tungsten oxide layer changes its transmittance when a voltage is applied between the two transparent conductors. The ions needed for the charge transfer are provided by the counter electrode. The electrochromic layer and the counter electrode are separated by the ion conductor, the layer that is different in the two coating types. It can either be another ceramic thin film deposited directly on the electrochromic layer, or a polymer foil which will be sandwiched between two glass panes both containing parts of the layer stack [4 - 9]. When a voltage is applied ions will be transferred from the ion storage film to the electrochromic film or vice versa and alters the optical absorption properties of the electrochromic film [7]. As ions usually protons (H^+) or lithium ions (Li^+) are used.

METHOD

For the investigation of insulating glass units two measuring setups are used. The optical properties like transmittance and reflectance are measured angle dependently with the window stand developed at the University of Basel [1]. With it the transmittance and the reflectance can be investigated angle dependent from 0° to 75° angle of incidence over a wavelength range from 350 nm to 2150 nm. The g-factor is also determined with a home made set-up [3].

The required power for switching and holding a transmittance state was investigated with a METRA Hit 29S from the Gossen-Metrawatt GmbH. Two types of measurements have been performed: (1) the total power consumption of the system measured at the power line of the control unit and (2) the power consumption of the glass unit itself.

RESULTS

The investigated smart windows consist of the glass unit and a power supply with an integrated control unit, all provided by the producer. The dimensions of the invested EControl glass are 1200 x 600 x 29 mm^3 and 1400 x 785 x 25 mm^3 for the SAGE glass. The active area is 0.72 m^2 and 1.1 m^2 for the EControl and the SAGE glass, respectively. Further the SAGE glass has a middle electrode dividing the total area of 1.1 m^2 into two areas of 0.55 m^2.

The spectral transmittance for the five discrete states of the EControl glass for perpendicular light incidence is shown in figure 1. In figure 2 the spectral transmittance for the SAGE glass is shown which only has two states. As the transmittance for the dark state is very small the values of the spectral transmittance were multiplied by a factor of 20 for clearer presentation.

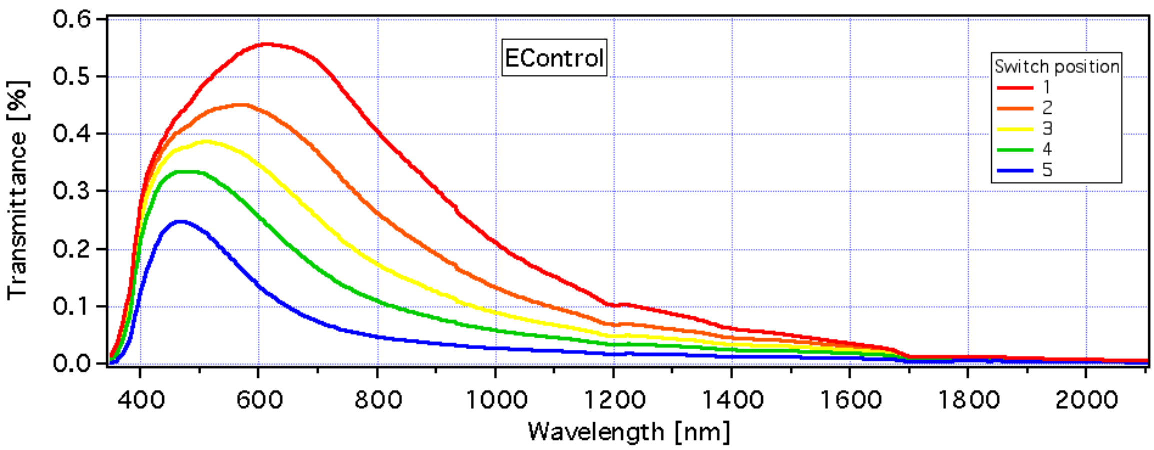

Figure 1: The spectral transmittance of the EControl glass for the five different switch positions, where 1 corresponds to the uncoloured and 5 to the darkest coloured state.

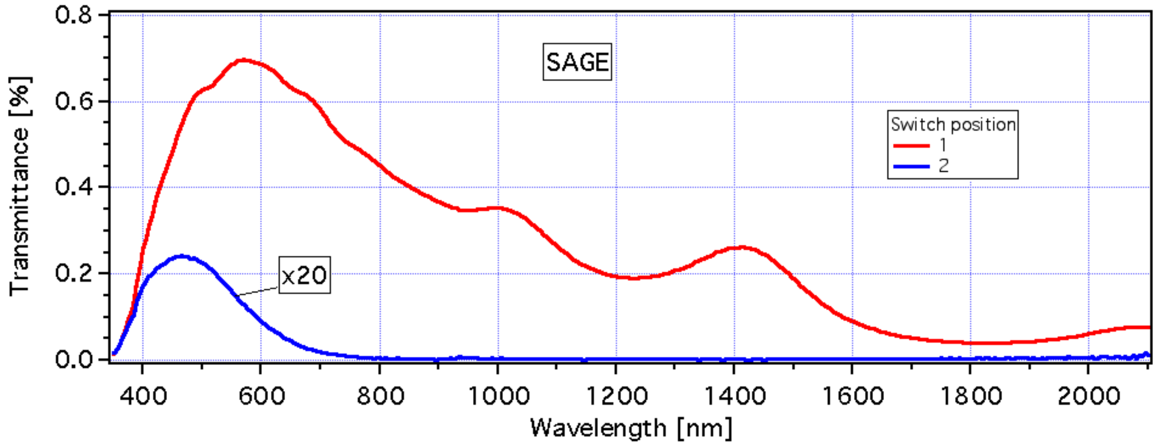

Figure 2: The spectral transmittance of the SAGE glass for the two different switch positions, where 1 corresponds to the uncoloured and 2 to the dark coloured state. The transmittance of the dark state is magnified with a factor of 20.

Comparing the transmittance of the bright state of the two glasses shows that the SAGE glass has a remarkably higher transmittance between 1100 nm and 1600 nm than the EControl glass. In the dark states of both glasses the reduction of the amount of incoming radiation having wavelengths greater 800 nm is greater than the reduction of the visible light (350 nm – 800 nm). Further the switching characteristic of the two products is different. The shape of the transmittance of the EControl glass is more or less constant for all states, whereas the shape for the SAGE glass changes.

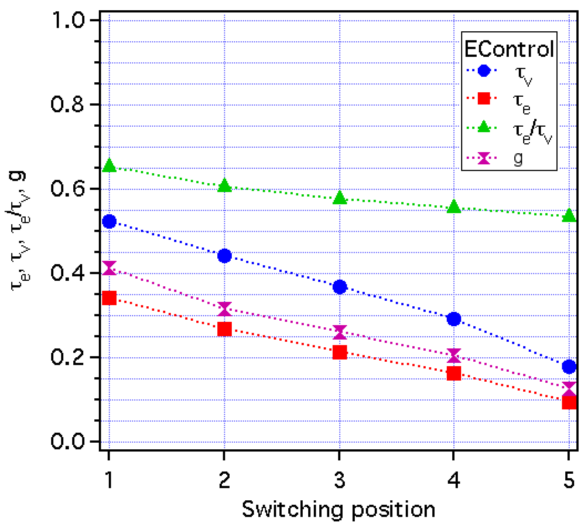

Figure 3: Light transmittance τ_v, solar direct transmittance τ_e, energy load coefficient τ_e/τ_v, and g-factor for the EControl glass depending on the colouring state. The markers give the values where as the lines are guides for the eyes.

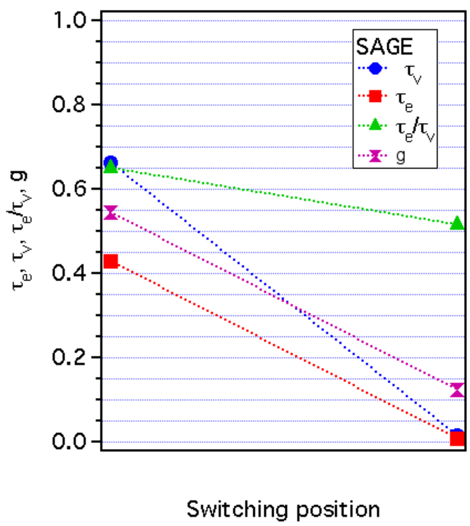

Figure 4: Light transmittance τ_v, solar direct transmittance τ_e, energy load coefficient τ_e/τ_v, and g-factor for the SAGE glass depending on the colouring state. The markers give the values where as the lines are guides for the eyes.

Light transmittance τ_v, solar direct transmittance τ_e, energy load coefficient τ_e/τ_v, and the total solar energy transmittance or *g*-factor are shown in figure 3 and 4 for the different switching states of the two glasses under investigation. In both cases the values decrease when switching to darker states and in the case of the five states of the EControl glass they posses a linear change. In table 1 the values for the bright and the darkest state are given.

	τ_v		τ_e		τ_e/τ_v		g-factor	
EControl	0.53	0.18	0.34	0.10	0.65	0.53	0.41	0.13
SAGE	0.66	0.02	0.43	0.01	0.65	0.52	0.54	0.13

Table 1: The value obtained for the bright and the darkest state of the two windows under investigation.

Comparing the values for the two glasses shows, that the energy load coefficient τ_e/τ_v is for the bright state of both glasses the same and nearly the same in the case of the darkest state. This means, although the solar direct transmittance τ_e at the bright state of the SAGE glass is higher it has the same selectivity (τ_v/τ_e) as the EControl, as its light transmittance τ_v is also higher. For the dark states it is the other way around. The g-factor is 0.13 for the darkest states of both and for the bright state 0.54 for the SAGE and 0.41 for the EControl glass. The g-factor of the SAGE glass in its dark state is with g = 0.13 unexpectedly high in view of the extremely low $\tau_e = 0.01$ value. The reason for this is the high direct solar absorptance $\alpha_e = 0.89$ of the active coating combined with a high heat conductance towards the interior glass pane leading eventually to a high secondary internal heat transfer factor $q_i = 0.12$.

The switching dynamics of smart windows is an important issue for usage and comfort. The evolution of light transmittance τ_v, solar direct transmittance τ_e, and energy load coefficient τ_e/τ_v versus time for the two glasses under investigation are given in figure 5 and 6. As can be seen in fig. 5 bleaching of the EControl glass goes faster than fully colouring it to state 5. For the SAGE glass the time needed to go from one state to the other is independent of the direction. The duration for a complete colour change for the two glasses is different. The EControl glass needs 700 s to change from state 1 to 5. This corresponds very good with the 12 min given by the manufacturer for a 1m x 1m window [8]. The time given by SAGE is 5-10 min for changing, for the investigated unit the time obtained in our experiment is around 15 min [9].

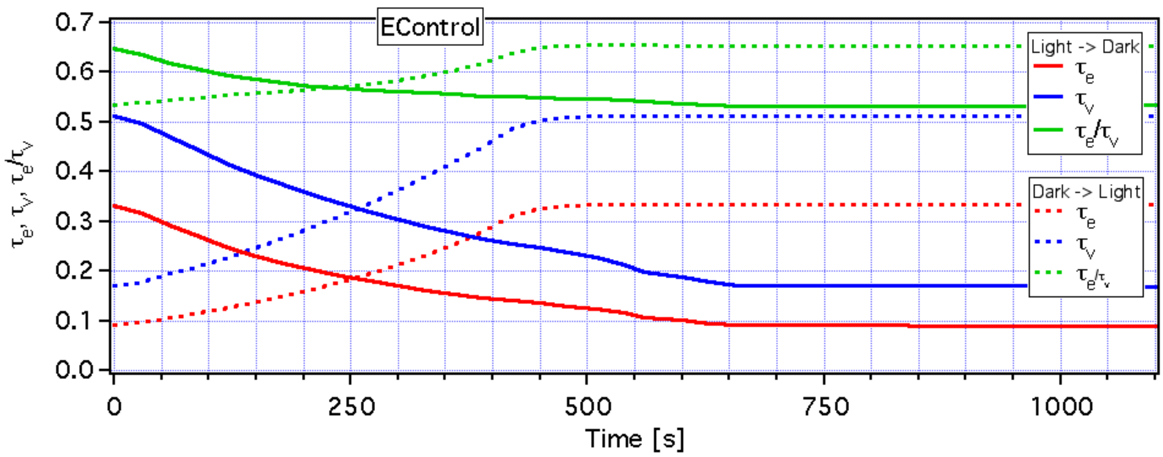

Figure 5: The evolution of the light transmittance τ_v, the solar direct transmittance τ_e, and the energy load coefficient τ_e/τ_v for the EControl glass, when switching from brightest (1) to darkest (5) transmittance.

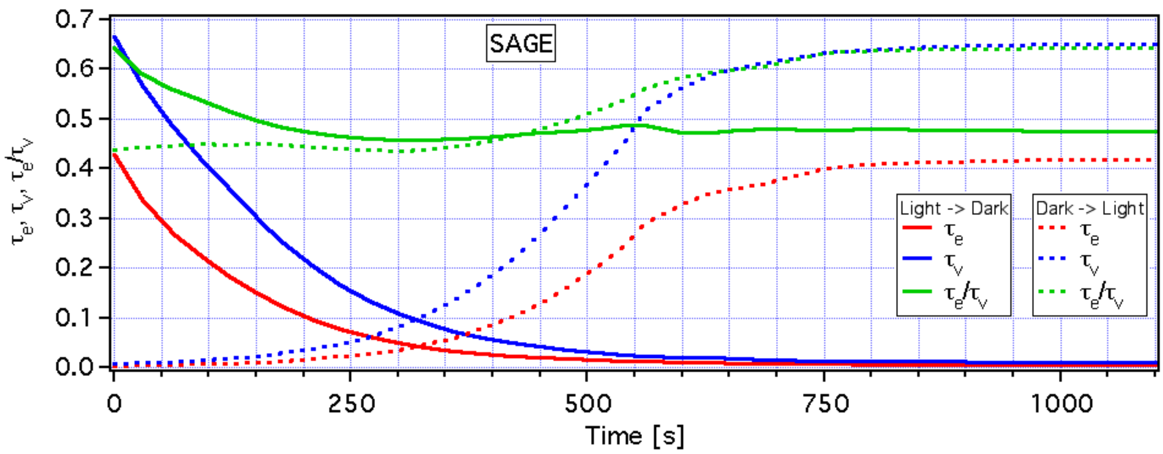

Figure 6: The evolution of the light transmittance τ_v, the solar direct transmittance τ_e, and the energy load coefficient τ_e/τ_v for the SAGE glass, when switching from bright (1) to dark (2).

The power consumption by the glass and by the system during changing and keeping the optical properties of the coating for the two investigated windows are shown in figure 7 and 8. In both graphs the yellow und blue lines represent the power needed by the glass unit, whereas the red and green give the total power of the system. The power consumption for the system and the glass are determined in individual measurements. For comparing the two graphs one has to keep in mind that the scale of the power axis is not the same.

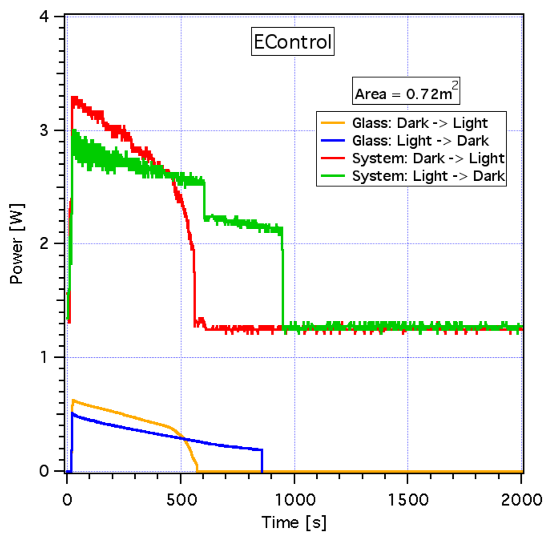

Figure 7: Power consumption of the EControl glass during the switching from the bright (1) state to the darkest (5) state or vice versa and afterwards keeping this status.

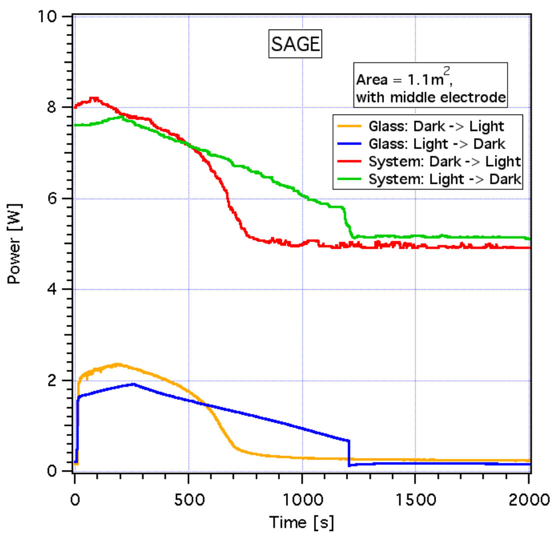

Figure 8: Power consumption of the SAGE glass during the switching of one colour state to the other and afterwards keeping this status.

Comparing the power usage of the coating of the SAGE and the EControl glass shows that the peak power needed for the EControl glass is 0.63 W (0.9W/m^2) whereas it is for the SAGE glass with 2.37 W (2.2W/m^2) much higher. The main difference is the SAGE glass needs 0.23 W (0.2W/m^2) to keep the transmittance state where as the EControl glass here for needs no power. Taking also the losses of the power supplies in to account the power consumption during constant transmittance is 8.2 W (7.5W/m^2) and 3.3 W (4.5W/m^2) for the SAGE and the

EControl, respectively. If the units are disconnected the EControl glass stays in its current state, whereas the SAGE bleaches to a state that is nearly equal to its bright state.

DISCUSSION

From these investigations, not taking the life cycle performance into account, we can conclude that both smart windows can increase the comfort in the building as they reduce the light transmittance without using blinds. Further they reduce the solar transmittance in the dark states and therefore reduce the heating up of buildings. To fully profit from those properties it is of great importance to choose the right glass for a specific usage. For example it would make sense to use the SAGE glass for overhead windows (skylights) as the transmittance can be reduced drastically down to only 2%. Using the SAGE glass in glass façade would increase the need of electrical lightening in the rooms and by the daylight reduction the comfort of the occupants is also reduced. Here the usage of the EControl glass would be advisable as the transmittance can be adapted to the light needed in the building.

Things that would need further improvement is the power consumption of the power supplies, especially during constant transmittance, as during this time the glasses need little or even nothing to keep it. Further a reduction of switching time would increase the comfort for occupants. Changing the coatings to receive a better selectivity would be another improvement, although they can already contribute to smaller cooling loads needed in buildings with the selectivity they posses now.

ACKNOWLEDGEMENTS

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