A detailed characterization of commercial electrochromic devices for building applications

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Abstract

In the modern buildings, the dynamic envelope, changing its solar, thermal and luminous properties, offers good opportunities for efficient energy use, taking into account also the comfort of occupants. Electrochromics windows, now available on the market, change their optical properties when a small voltage is applied to the conduction layers of the glazing and, as a consequence, are suitable components for such kind of technology. Some basic performance indexes are required to let these components be appropriate for building applications.

An optical characterisation of chromogenics glazings requires additional measurements and analyses respect to the static components. The optical properties depend on the voltage applied to the conduction layers of the electrochromic system and the switching time is an important issue to analyse too. This paper aims at giving some useful data for the application of smart windows in residential and commercial buildings.

1 Introduction

The building sector, both commercial and residential, is responsible of a relevant part of energy end use in Europe and several actions are carried on to help the reduction of the fossil fuel consumption and the reduction of greenhouse gases emissions. Such activities are carried on at different levels and one of the most important is the research on new and efficient materials and, as the next step, their correct integration in building components or in the whole building itself.

The research on the electrochromic systems is going on since many years, electrochemical reaction are known since lot of time, but the idea of the electrochromic glazing for building application is relatively recent. One of the major problems was the deposition of the several thin layers over huge surfaces (as the window can be considered in this case), lot of studies were carried on to improve the homogeneity of these glazing systems as well as their durability. Now, few producers are finally able to sell chromogenic and electrochromic windows.

This paper deals with characterisation of commercial electrochromic glazing units of different dimensions. Static and dynamic measurements were performed with different experimental set up and by simple observation of transitory phases. The results aim at giving a useful and detailed optical characterisation of such devices, for their better integration in buildings.

2 Chromogenic research activities in IEA – TASK 27 and SWIFT EU Project

The importance of the building stock in the energy end use and the progress achieved in the fenestration sector during the past years lead to an intense research activity, with a lot of institutes involved in common research projects at European and international level. The smart glazings represent, from this point of view, an important subject because of the research needs in terms of materials, components, building integration issues as well as people safety and comfort.

The Solar Heating and Cooling Programme of the International Energy Agency set up the Task 27- Performance of Solar Facades Components to improve the performance, the durability and the sustainability of solar components to be integrated in the building façade. In this task two working groups were established to investigate on the energy performance and durability of chromogenic glazings. The activities involve several researchers, coming from European and USA institutions, and representatives of industries. Research activities include the measurements and modelling of luminous, solar and thermal properties of smart glazings, the evaluation of energy performance of buildings equipped with such devices and the users preferences concerning their visual and thermal comfort in working place equipped with chromogenic windows. These actions will be important outputs of IEA Task 27 that started in 1999 and will be completed by the end of 2003.

Important activities are also underway in Europe, the SWIFT (Switchable Façade Technology) project, funded by the European Communities within the V Framework, started in 2000 and will finish in 2003. The working group, in which are involved universities, research institutes and industries of several European countries, investigate the potentiality of chromogenic glazings in building application.

The research concerns with electrochromic and gasochromic glazing systems, supplied by the industrial partners. The main fields of the research are: the optical and thermal characterisation, the reliability and durability, the building integration, the sustainability and the potential market to help the application of such advanced systems in new and renovation buildings.

3 Experimental

The experimental work consisted in performing transmittance measurements with two large integrating spheres. Two instruments were needed because of the different experimental outputs. The laboratory measurements were performed on a 50x50 cm commercial sample by Flabeg (www.flabeg.com) , the same type of electrochromic glazing was used for the window of the ENEA experimental building “Casa Intelligente”. The sample is a double glazing unit with an electrochromic outer pane (9 mm), an air gap filled with argon and an 4 mm inner pane with heat reflecting coating. In figure 1 is window of the building with one pane clear and the other fully coloured presented.

The ENEA integrating sphere

The ENEA sphere, see figure2, is an arrangement of equipment and instruments for the measurement of the spectral optical properties of advanced transparent materials. [1]

The main component is the integrating sphere having a 100 cm diameter. The sphere is made of aluminium with an inner coating having a reflectance coefficient bigger than 0.97-0.98 in the visible range (400-800 nm) and bigger than 0.80 in the whole solar range (up to 2500 nm). The sphere has several ports, which are needed for a proper execution of the measurements. Referring to figure 2, P1 (7) is the sample port (with variable diameter ranging from 12.5 to 30 centimetres), through which the beam emitted from the light source enters the sphere. The 2.5 cm detection port Pd1 (6) at the bottom of the sphere allows the measurement of the luminous intensity present inside the sphere.

The auxiliary port, P2 (8), is necessary to determine the substitution errors correction factors, needed for the transmittance measurements. [2]

Figure 1 Electrochromic window at ENEA experimental building

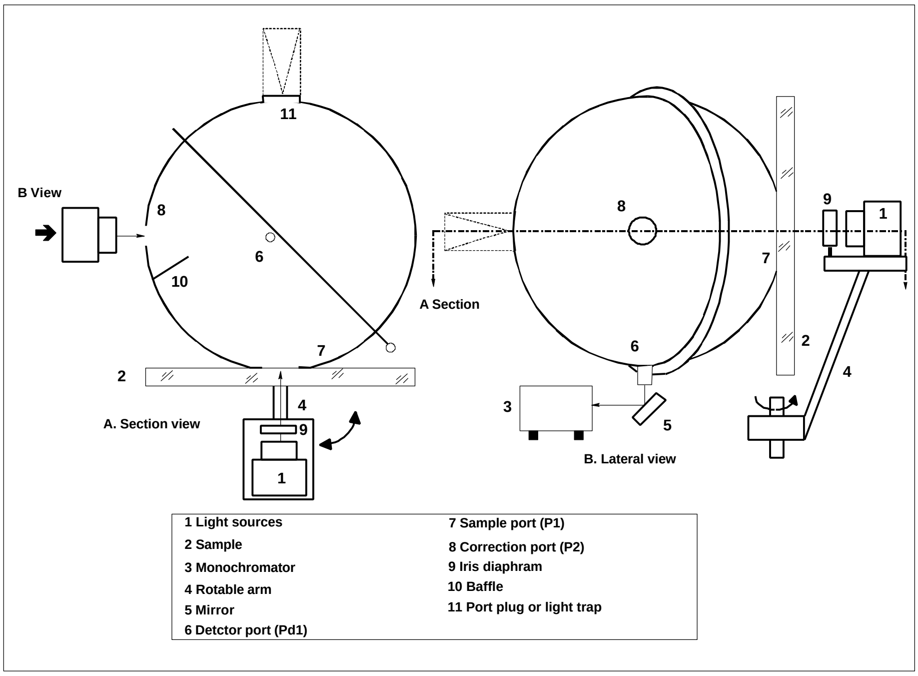

Figure 2 ENEA integrating sphere

The light source is mounted on the rotable arm (4) in order to allow off-normal transmittance measurements. The position of the beam can be adjusted using the three axis movement system supporting the light source. With this equipment it is possible to perform measurements up to 60° as angle of incidence.

Two light sources allow the optical characterization in the whole solar spectrum (250-2200 nm): a 300 Watt Xenon arc lamp and a 1000 Watt Quarz Halogen lamp are utilized for measurements in the visible (250-1100 nm) and near infrared (1100-2200 nm) range, respectively. Both are equipped with very stable power supplies.

The optical spectrum analyser has a silicon detector and a PbS detector for visible and near infrared range. The entrance slit of the monochromator is directly coupled with the detector port by a tilted mirror. The wavelength steps generally used are 5 nanometers for the visible and and 10 nanometers for the near infrared range.

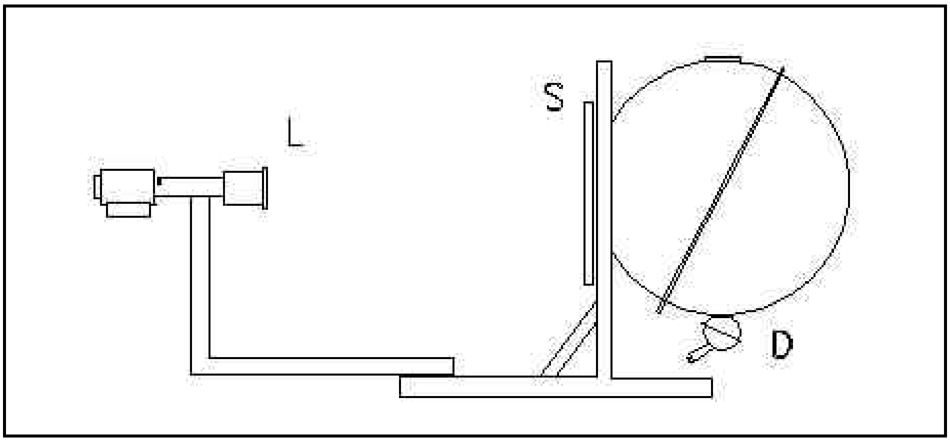

Figure 3 SSV integrating sphere in the transmission configuration. L: light source; S: sample; D: detector.

The SSV integrating sphere

The SSV large sphere has a diameter of 50 centimetres and can be used for the optical broad band characterisation of conventional and complex ???? glazings. The layout of the system is presented in figure 3. An almost collimated unpolarized light beam (simulating illuminant A) hits the sample and the transmitted or reflected beam is collected by the integrating sphere.

The reflectance measurements are performed by rotating the integrating sphere around a vertical in the sample plane: the light beam enters through one of the reflectance ports of the integrating sphere and then hits the sample. The design of the equipment allows that the distance between the light source and the sample does not change in the transmittance and reflectance configurations.

The cross-section diameter of the light beam incident on the sample is 30 mm. The comparison method can be used (diameters of both the sample and auxiliary ports: 50 mm). Larger sample ports with diameters of 167 mm and 200 mm can be used to perform angular measurements or to measure large-angle diffusing samples [3, 4]. The cosine-corrected detector is a satellite integrating sphere with a diffusing glass sheet at its entrance port and a silicon photodiode whose sensitive area lies within the internal surface of the sphere. A screen prevents the direct illumination of the satellite integrating sphere by the sample.

4 Results

The ENEA integrating sphere was used for performing spectral and angular measurements on the electrochromic device. The spectral analysis is performed in the range between 350 and 1150 nanometers, the wavelength step was 5 nanometres between 350 and 800 nanometres, and 10 between 800 and 1150 nanometres. 80% of the solar energy falls in. the scanned spectrum range.

The spectral transmittance of the sample is plotted in figure 4, the five curves refers to the five states that can be set with the glazing control system. The angular transmittance curves, obtained by interpolation of experimental data at 0, 30, 45 and 60 degrees, are plotted in figure 5. The measurements were performed with the electrochromic glazing in the bleached and fully coloured positions and the integrated results are obtained using the Illuminant A as weight. In table 1 the numeric result are reported.

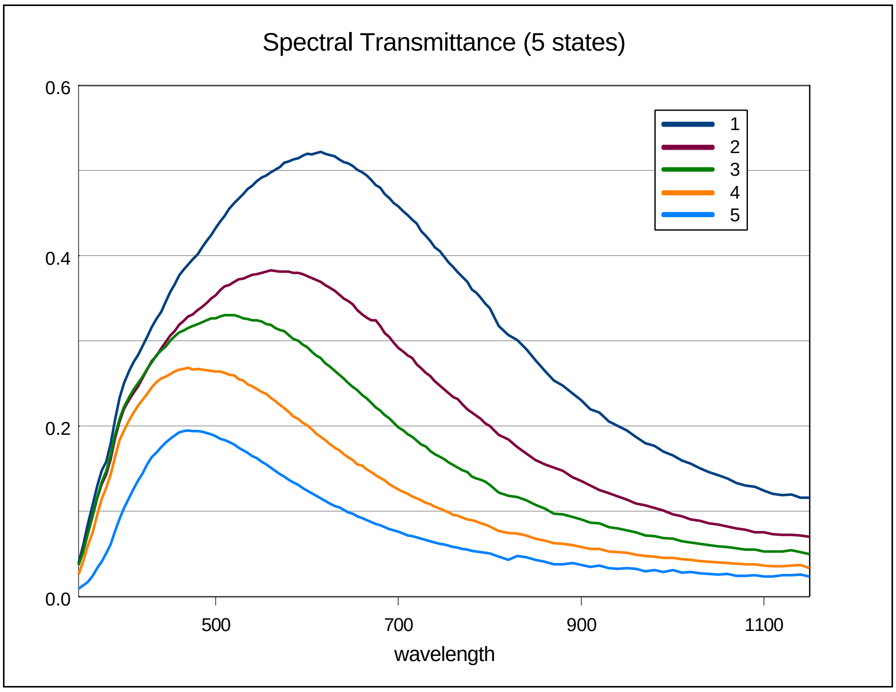

Figure 4 Spectral transmittance curves in the 5 states of the EC glazing

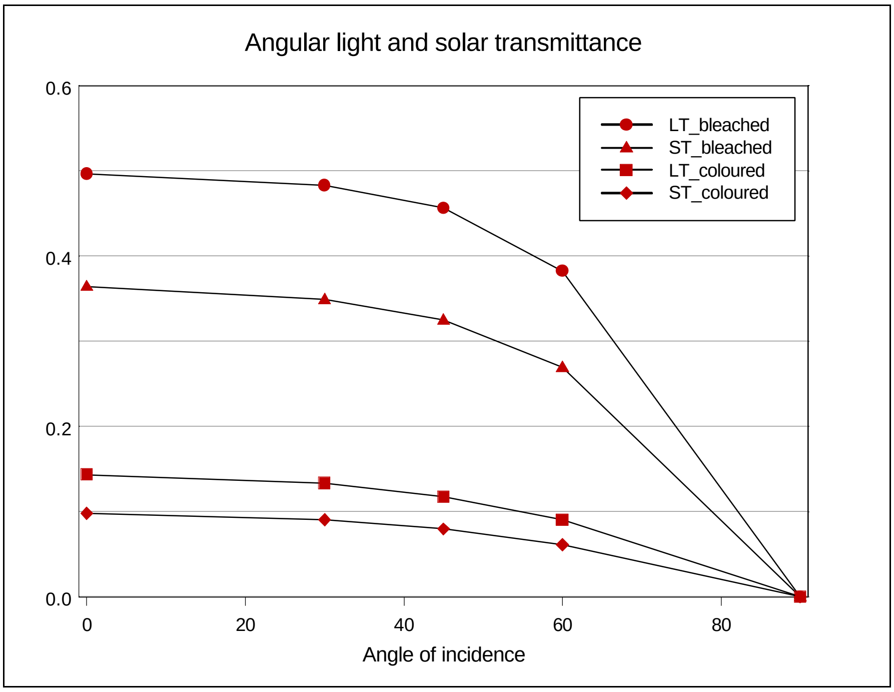

Figure 5 Light and solar angular transmittance of EC glazing

Table 1 Angular transmittance measurements

θ [°]	τ_v [%] bleached	τ_e [%] bleached	τ_v [%] colouerd	τ_e [%] colouerd
0	49.7	36.5	14.4	9.8
30	48.3	34.9	13.3	9.1
45	45.7	32.5	11.7	8.0
60	38.3	27.0	9.1	6.2

One more set of measurements was carried on with the ENEA sphere to evaluate the homogeneity of the sample. Three measurements were performed at normal incidence in different spots of the sample: in the centre, close to one edge and close to one corner, as showed in figure 6. These measurements were performed in the visible range only, with a step of 10 nanonmeters. The light transmittance values, integrated with the usual Illuminant A, are reported in Table 2.

Table 2 Homogeneity measurements

	1 (centre)	2 (side)	3 (corner)
τ_v [%]	14.6	14.2	14.3

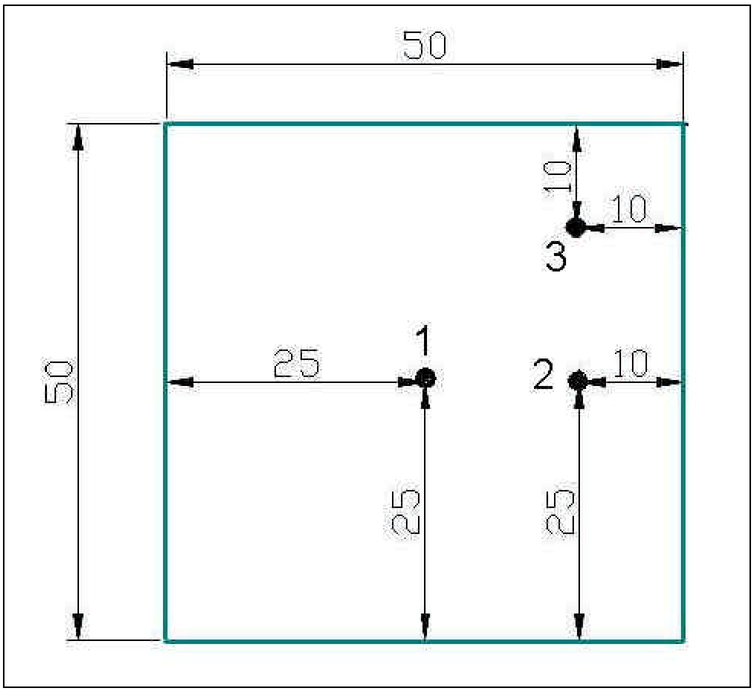

Figure 6 Measurement spots for homogeinity evaluation

The SSV sphere was used to evaluate the decay of the transmittance during the transitory phase, this data can be useful for combined daylighting and energy analyses, with accurate data to be used as input. This facility directly measures the light transmittance (with Ill. A), and it possible to make several readings in short intervals. In this case it was decided to measure the light transmittance during the transitory and the results are presented in figure 7. Observing the graph, it is clear how the curve steeply decreases during the first minutes, then the curvature changes and the profile is flat until the process finishes. The transitory was longer than expected but this can depend on the low temperature and the darkness of the room, in fact in these environmental conditions the electrochromic requires more time for changing its status.

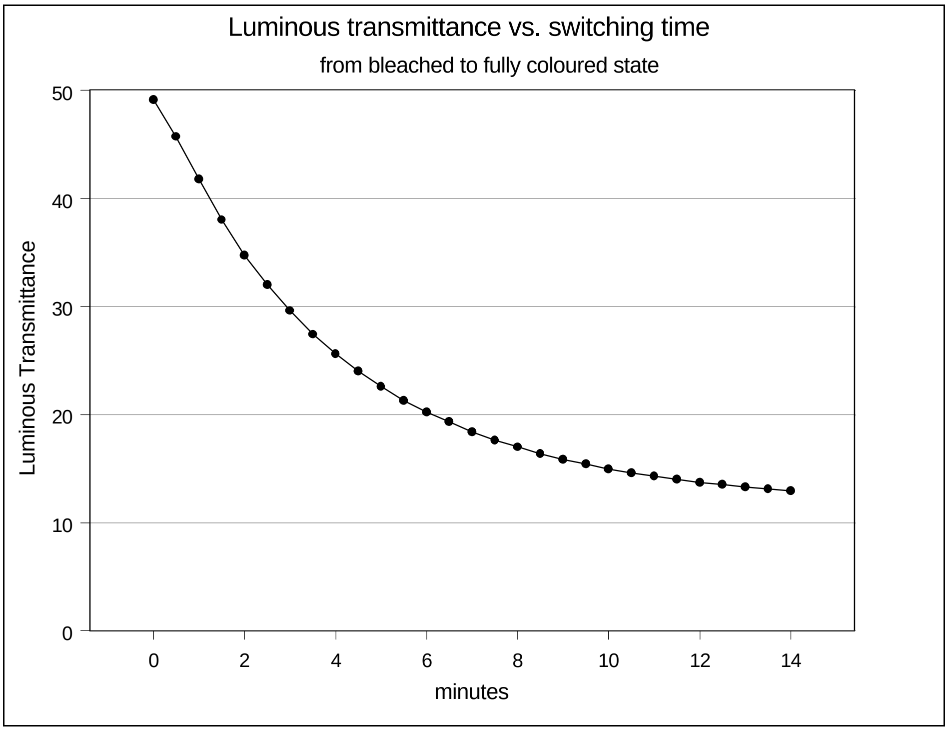

Figure 7 Temporal decay of light transmittance during the transition

Conclusions

It is important reminding, before next comments, that the sample on which the measurements were performed, is part of a stock bought by ENEA for equipping the experimental building “Casa Intelligente”, because of several delays the EC components were not switched for more than one year. This long un-operating period made the glazings to loose their initial performance and it was necessary to have a re-activation procedure by the glazing producers. After many cycling the glazing started performing better, and they reached the optimum performance level for this set of measurements.

The optical measurements showed very good performance of the tested samples. One of the basic requirements generally required for chromogenic glazing is to have the transmittance in the dark state at least three times lower than in the bleached state. According the above results, this requirement is largely achieved for both light and solar transmittance.

The homogeneity measurements yielded good results as well, even if measured in very different positions of the glazing. It must be noted that the differences of the results in the selected spots of the sample falls into the error band of the instrument.

The measurement during the transition phase gave the expected results, with a steep decreasing of the transmittance during the first minutes and more flat behaviour in the last portion of the transition. These results can usefully be applied for daytlighting simulations, since the dynamic rendering of the indoor environment changing versus the time, can be simulated according to the real behaviour of the electrochromic window.

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