Illuminance measurements and thermal analysis of test rooms equipped with high performance electrochromic glazing

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Keywords

1=electrochromics 2=electrochromic glazing 3=smart windows 4=solar control

Abstract

Electrochromic smart glazing prototypes of about 1 m^2 were tested in a PASSYS cell and in an office room for about 1 year. During that period illuminance and thermal measurements were performed in dependence of weathering conditions, seasons and different control strategies of switching. A lot of data were collected. The data analysis delivers important results regarding energy control properties of that windows. A good performance of the panes in the visible and near infrared spectral region (τ_V, τ_e) is an essential requirement for function and advanced energy saving properties. Only with a well adapted switching control of the panes the additional features can be used: preventing glare and overheating in the summer and enabling solar energy gain in the winter. Details on optical switching behaviour and results of solar radiation control tests in facades are presented.

Introduction

Prominent features of modern architecture are the demands for large glazed areas and the related high visual and thermal comfort inside the buildings. However in moderate climates due to seasons change very different weathering conditions occur. In winter the glass envelope of a building should be highly transparent and heat insulating – for heat saving, a maximum daylight use and high solar energy gain. In summer the glazing should block intensive solar radiation transmission to prevent overheating and sun glare. Until today no conventional glazing system can satisfy both requirements, because all available glazing have static values of light transmittance (τ_V) and solar transmittance (τ_e). A glazing with optimum solar protection properties prevents overheating and glare in the summer but the daylight use and solar energy gain in winter is diminished to a minimum. Low-E glazing with high τ_V and τ_e values could save energy for heating and lighting in winter, but they lead to overheating and sun glare of the rooms in summer. Between these types there are a lot of other glazing available, but it has to be decided for every building, may be for every facade, what is more important for energy efficiency, solar protection or energy gain.

An optimum adaptation of glazing to changing seasons and weathering conditions could be supplied by a switchable electrochromic glazing (EC-glazing). Such a glazing can switch light and solar transmittance and can so fulfil all requirements. The construction of the electrochromic glass of Gesimat GmbH is shown in figure 1. Two glass panes with transparent conducting layers are coated with complementary electrochromic films (tungsten oxide and Prussian Blue) and laminated together by use of an ion-conducting PVB sheet of TROSIFOL. This EC-glazing reaches a very high light transmittance of about 77% at completely bleached state combined with very low light transmittance of 8% at fully coloured state, see spectral distribution in fig. 2. The solar transmittance switches from 56% down to 6%. For further details of performance and construction of Gesimat electrochromic laminated glass see references [1, 2].

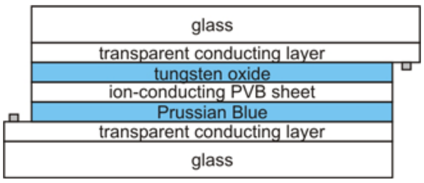

Figure 1

Schematic drawing of the construction of the electrochromic laminated glass developed by Gesimat and partners [1].

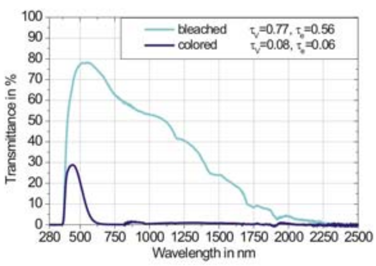

Figure 2

Spectral Transmittance with calculated visual and solar transmittance for totally bleached and fully coloured state of an electrochromic laminated glass of Gesimat.

Experimental

Field tests with EC-glazing were performed at a PASSYS cell and an office room for about 1 year. Both are located in Cottbus (Germany) at the campus of the Brandenburg Technical University (BTU). The PASSYS test cell (fig.3) has a size of 2.70x2.70x5.0m [3]. The facade is south orientated and was equipped with 3 electrochromic insulated glazing units (EC-IGU) by size of 1200x800mm. EC-IGU's had a 16mm air filled gap with EC laminated glass outside and a 4mm low-E glass with τ_V of 70% and g-value of 40% inside of the room. Within the PASSYS cell 5 illuminance sensors were installed at a height of 0.85m and with distances of 1m; 1.5m; 2m; 3m; 4m from the window wall. Furthermore sensors for air temperature and globe temperature measurements were used.

Figure 3

Front view of test room PASSYS cell

Figure 4

Front view of office test rooms, equipped with electrochromic windows (EC-IGU, blue circled) and conventional windows (IGU, white circled).

In a second experiment EC-glazing were tested in an office room. The test area consisted of two identical side by side unused office rooms (fig.4). The first room was equipped with conventional windows (IGU) and the second with electrochromic windows. The EC-windows consisted of electrochromic laminated glass (outer pane), a 10 mm air filled gap and an interior 4mm K-glass pane. Both rooms face west and the transparent area of the double glazing windows was 1.35 m². The two office rooms were equipped with several sensors for the determination of the illuminance, the air temperature, the globe temperature (for the radiant temperature), the air velocity and the humidity. Illuminance was measured at distances of 1m, 2m, 3m from the window wall. Luminance pictures, made by a calibrated luminance camera, were used for the evaluation of glare on the windows and on the walls besides.

Figure 5

Picture of inside view of PASSYS cell at bleached EC-windows on 29.08.2005, 9.00 p.m.

Figure 6

Picture of inside view of PASSYS cell at coloured EC-windows on 30.08.2005, 9.00 p.m.

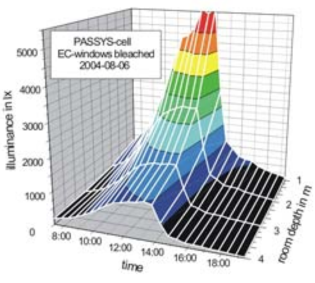

Figure 7

Indoor illuminance over a bright sunny day in dependence of room depth, EC-windows bleached.

Utilisation of daylight

Daylight is a very pleasant, natural and energy-efficient light source for buildings and offices. For the extensive use of daylight in buildings it is required to adjust the very unsteady sunlight to the user's demand. In the following results of illuminance measurements at PASSYS cell with south orientated facade and at office rooms with west faced facade are presented.

Illuminance measurements in PASSYS cell

Figure 5 and 6 show pictures of view from inside to outside of PASSYS cell with electrochromic windows at bleached and coloured states. Both pictures were made by using a calibrated digital luminance camera with equal recording adjustments (aperture 8, exposure time 1/20sec) at equal times of two following days with constant sunny weathering conditions. At bottom and left of the pictures installed measuring sensors are visible.

With a depth of 5 m PASSYS cell was very suitable for analyse of indoor illuminance in relation to room depth. In figures 7-9 indoor illuminance of PASSYS cell over the whole day in relation to room depth is plotted as 3 dimensional plot. At bleached EC glazing illuminance reaches at 1m distance from the window at high noon more than 5500lx (fig.7). This is too high for office rooms and produces glare at desks and screens. At full coloured electrochromic windows the illuminance reaches 500lx only around high noon (fig.8). Other areas of PASSYS cell are too low illuminated for working and would require an additional illumination. The minimum value of illuminance at desks in office rooms is 500 lx, as recommended in some standards (e.g. DIN5035-2). For qualified work at working desks, a little bit higher illuminance up to 1000lx is often desired [4].

Much better indoor illuminance was achieved by computer controlled EC-switching. The transmittance of the electrochromic windows was automatically adjusted based on an illuminance sensor at a distance of 1.5 m from the windows, to provide a daylight illuminance at this point between 1000 lx up to 1070 lx (fig. 9). The three-dimensional plot of room illuminance at computer controlled switching shows optimum values around 1000lx up to 2m distance from the window wall nearly over the whole working day and sufficient illumination between 2 and 3m distance. At further room depth with higher distance from

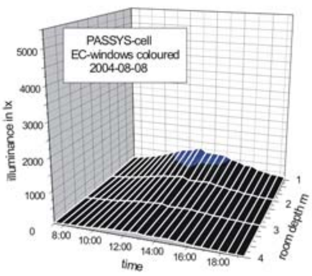

Figure 8

Indoor illuminance over a bright sunny day in dependence of room depth, EC-windows coloured.

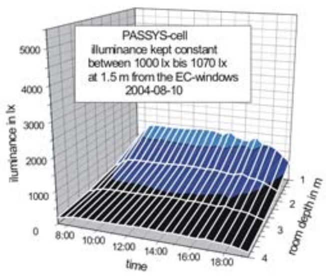

Figure 9

Indoor Illuminance over a bright sunny day in dependence of room depth, EC-windows switched by illuminance control between 1000 and 1070lx.

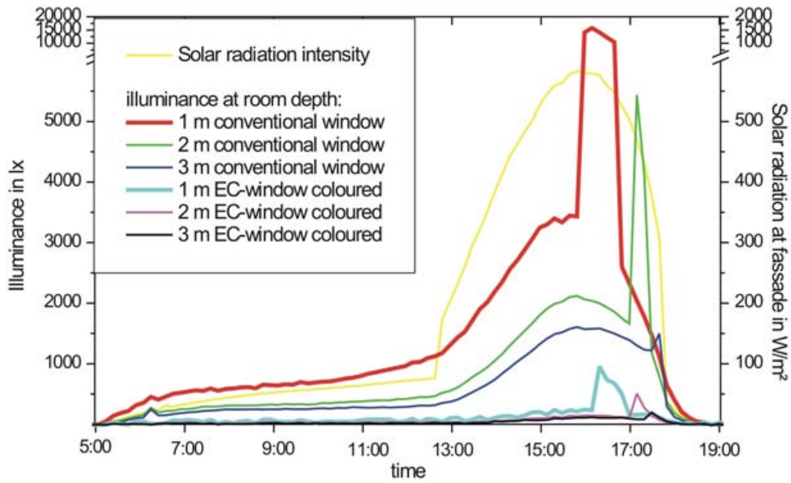

Figure 10

Illuminance measurements in the office rooms with conventional and electrochromic windows at different distances from window the window the illumination retains below 500lx. Disturbing glare could be prevented at every time. No additional solar protection of a south faced façade, equipped with Gesimat electrochromic glazing is required.

Better daylight illumination of rooms with high room depth could be achieved if the windows of the façade would be divided into lower and upper parts which could be switched separately. In such cases the lower panes could be switched for optimum working desk illumination near the window whereas the transparency of the upper panes were adapted to provide a maximum daylight gain without any glare for workplaces away from the façade [5].

Illuminance measurements in office rooms

A maximum illuminance of about 15.000lx were measured in the office room with conventional windows without shading at a distance of 1m from the window wall (fig.10). This is much too bright for workplaces and would cause glare on desks and screens. The high peaks at the illumination curves appear due to the west warded façade. From about 4 p.m. up the sun is shining into the room and illuminates directly the sensors.

In the neighbouring room with fully coloured electrochromic windows at the same time the illuminance retains below 1000lx also in the case of direct solar illumination. With increasing distance between windows and measuring points the illuminance decreases rapidly.

Optimum illuminance of workplaces is not sufficient alone for lighting comfort. The maximum value for the mean luminance of surfaces, which could reflect on a screen and so could cause glare and disturbing reflections is 1000 cd/m². More than 5700 cd/m² were measured on the wall for the light spot of the bleached window, whose transparency is similar to a conventional window (fig. 12). In contrast to that only 1295 cd/m² were measured for the coloured window. These values show the potential of the electrochromic glazing to prevent glare even if the limit value of 1000 cd/m² is not kept in all cases. The wide reduction of the luminance is sufficient in most cases, because some more luminance on few surfaces (windows, light spot) should be accepted for the benefit of sufficient natural daylighting and illuminance.

Thermal comfort in the office rooms

Thermal comfort is defined in the EN ISO 7730 standard as a matter of many physical parameters. The heat produced by the metabolism of the human body should be equal to the amount of heat loss from the body. The so-called Comfort Equation describes the connection between the measurable physical parameters and thermally

Figure 11

Office room with electrochromic windows: real picture. 22nd September 2005 at 2 p.m., clear sky; left window bleached, right window coloured

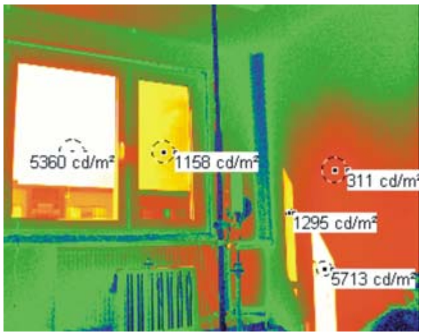

Figure 12

Office room with electrochromic windows: false coloured plot of picture of fig.11

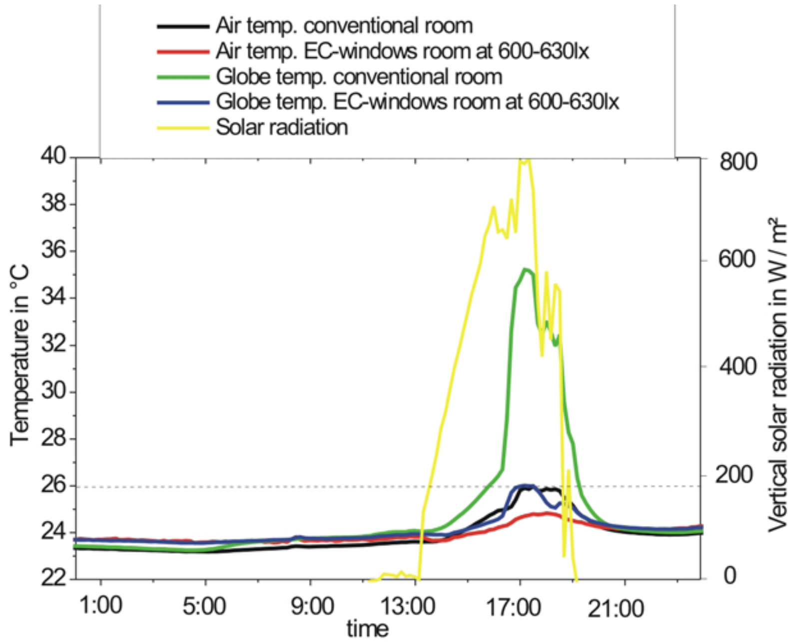

Figure 13

Comparison of temperatures between the office room with conventional windows and the corresponding room with automatically adjusted illuminance at 600 lx - 630 lx by electrochromic windows, May, clear sky

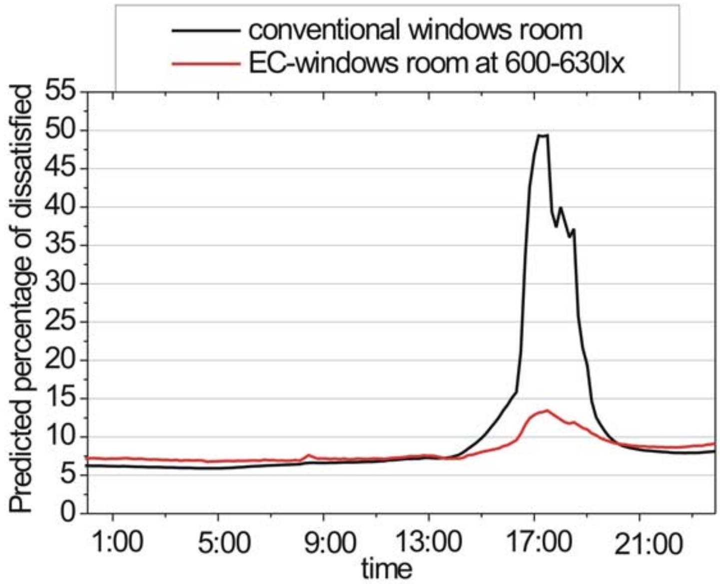

Figure 14

Comparison of PPD between the office room with conventional windows and the room with automatically adjusted illuminance of 600 lx - 630 lx by electrochromic windows, May, clear sky neutral sensation as experienced by an average person. Some input parameters are to measure namely the air temperature, the globe temperature (for the radiant temperature), the air velocity and the humidity (Fig. 13).

In this test the work plane illuminance in the room with the electrochromic windows was adjusted in the range from 600 lx to 630 lx, which are very comfortable values. The secondary effect of this adjustment is a lower globe temperature of only 26 °C in this room compared with about 35 °C in the room with conventional windows without any shading (fig.13).

One result of the Comfort Equation is the predicted percentage of dissatisfied persons (PPD). The statistically best result is 5 % and the worst is 100 %. The PPD-value of the room with electrochromic windows is in the maximum 13 % and thus significantly lower than in the conventional room with up to 50 % (fig. 14).

The investigation has shown that electrochromic glazing are an effective sun protector. There is an uniform lighting of offices especially in combination with an automatic adjustment of the windows transparency. The thermal comfort is much better than in the room with conventional windows.

Conclusion

It could be shown that the electrochromic laminated glazing of Gesimat is well suited for smart switchable windows in architectural applications due to its wide switching range of more than 65% visible transmittance (τ_V=8% coloured, τ_V=77% bleached). Its future use in commercial and residential buildings will result in more comfortable working and living spaces as well as in a reduction of energy consumption.

Acknowledgements

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