Luminous monitoring of a test room equipped with electrochromic windows

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ABSTRACT: The experimental building “Casa Intelligente” (Smart House) at ENEA is one of the first buildings equipped with electrochromic windows. The chance of modifying the visual and solar parameters of glazed facades is an important option to optimise the energy performance of building as well as the comfort conditions for users. This paper presents the results of an experimental campaign, aiming at the evaluation of the luminous conditions in a test room of the experimental building, to explore potentialities and limits of these innovative products. The monitoring was carried out during three periods corresponding to the winter and summer solstices and the autumn equinox. The room was equipped with a grid of nine luxmeters at the typical working plane height, measuring the horizontal illuminance, the external illuminance was also monitored. The monitoring was run for the windows in the following conditions: always in the clear state, both windows fully coloured and alternatively coloured, according to the orientation and the sun position. The results of this preliminary experiment are useful to evaluate how actual switchable glazings can to ensure the visual comfort and to optimise the diffuse and the direct daylight transmission.

Conference Topic: 5 Materials and building techniques
Keywords: daylighting, visual comfort, smart glazing

1. INTRODUCTION

Modern buildings, especially in the tertiary sector, area characterised by a massive use of glazed surfaces, which cause a strong increment of cooling (and, as a consequence, electricity) loads. This problem is getting critical in hot and temperate climates, i.e. the Mediterranean area, where the simultaneous demand of electricity is the main cause of energy management problems at the building level, as well as at urban level.

To overcome, partially at least, such problems, the dynamic building envelope is one of the most attractive issue of the modern architecture. Dynamic envelope can be focused on the application of different techniques to improve the energy performance of buildings as: hybrid ventilation with double skin facades or renewable (i.e. photovoltaic systems) energy integrated in the façade. The use of large glazed area make makes the building envelope permeable to the solar radiation, which means useful solar gains in winter but very strong cooling loads in summer. The possibility of modulating the solar energy transmitted through the envelope, by adequate dynamic shading, is an added value to optimise the energy performance of buildings.

Electrochromic (EC) glazing materials, whose effect was firstly described in 1969 [1], change their colour, with associated change of optical and solar properties, through a small voltage applied to the external layer of the system. This technology permits regulating the energy flux entering into that building and the control of the colouration state can be applied as a function of thermal or visual comfort for users, or to minimise the building energy use, taking into account that the variation of the solar gains causes a variation of both, heating and cooling loads.

The experimental building “Casa Intelligente” (Smart House) is one of the first full size case studies of building integration of electrochromic windows. It was funded by the Ministry of Industry to provide knowledge in the field of domotic and home automation. Smart glazing, which can run manually or by remote control strategies, were a suitable technology to install. A first set of experiments, based on manual control, was performed in the past two years, here the results of an unoccupied room luminous monitoring are presented.

2. EXPERIMENTAL

The experimental building “Casa Intelligente” (Smart House) at ENEA was funded by the Italian Ministry of Industry, in order to carry on experimental researches to improve the energy performance, the safety, security and comfort for users, in residential dwellings. The main area to investigate is, in particular, the added value that smart domotic technologies can offer respect to the traditional solutions for heating, cooling, ventilation, lighting systems, as well as for the loads management. Since the dynamic envelope is an attractive issue in the modern architecture, the building was equipped with electrochromic windows, since this technology seems to be very promising and suitable for applications
where the automation of the building allows significant advantages.

The experiment was carried out in a room equipped with two EC windows, one south-east oriented and the other south-west. The glazings were supplied by Flabeg and their luminous transmittance can switch from 50% in the bleached state to 15% in the fully coloured state [2]. Each double glazing unit is made of an outer EC device, 8mm thick, and a 4 mm, low emittance coated glass. Both windows are 120 by 160 centimetres and they consist of two glazing devices 45 centimetres large and 130 centimetres high. The offset of the window respect to the opaque façade is 25 centimetres, this implies the presence of self-shading of the window-wall assembly, especially for high elevation of the sun. In this experiment the EC devices are manually operated by controllers, sold together with the glazing units, which allow the setting of different states. Due to the small surfaces of the window, it was decided to operate the glazings between the two extreme states only.

The room, whose layout is in figure 1, is around 30 square meters (5.9x5.2 meters). The room has a grey carpet, the walls are whit painted and the suspended ceiling is light grey. Figuring an office activity in the room, it was supposed to have two working desks parallel to the windows (zones A, south-east oriented and B, south-west oriented) and a table for small meetings in the south corner (zone C). Under this assumption, the required illuminance levels were respectively 500 and 300 lux. The two working stations are around 120 centimetres from the two windows.

The monitoring was carried out in three different periods of the year: summer, winter and spring, as close as possible to the solstices and equinox dates. The monitoring went on for several days (at least 7), but only some of them were considered for the evaluation, since only clear sky days were worth to be analysed. As a matter of fact, during the cloudy days the indoor luminous environment was quite dim because of the limited glazed area: moreover, the days with changing sky were not taken into account because of the difficult comparison between different days.

3. RESULTS

To make the results of the monitoring easier to read and understand, they were grouped according to the three different zones of the room. The illuminance on A and B is calculated as the average of the luxmeters 1+4 and 8+9 respectively. The illuminance in C is
calculated as the average of the luxmeters 2, 3, 5 and 6. This solutions was adopted taking into account that the working area can be quite large and the position can be also modified by the users, who as an example might prefer to be close or away from window.

The monitoring of the room run from 7am to 5pm. The first hour is supposed to be dedicated to the room cleaning, the working hours are scheduled from 8am to 5pm, according to typical Italian public schedules.

The results are summarised in Tables I and II. The maximum, minimum, daily, evening and afternoon average illuminance are reported for each zone and for outdoor. More over the number of hours in which the illuminance is lower than 500 and 350 lux is reported (300 and 200 threshold values for C). If the illuminance is higher than 500 (350 for C) lux, no artificial lighting is required. The 350 value was chosen as an indicator of a noticeable daylighting, eventually to be integrated by a limited artificial lighting switching on.

The height of the sun in this season and the self shading of the window wall assembly are important parameters for the illuminance distribution inside the room, in fact even with the glazing in the clear state the 500 lux are not reached for several hours. In table 1 the results are summarised. For position A and B it is found that the colouring both windows leads to low illuminance levels, which requires the integration of artificial lighting for almost all the day long. Colouring only the window exposed to the sun causes the use of artificial lighting, even if 350 lux are reached for several hours. Concerning the third zone, it is found that the bleached windows allow an acceptable illuminance level, but the simultaneous and alternative colouring of the windows implies the integration of the artificial lighting for almost all the day long.

| Table I Summer monitoring results. Indoor and outdoor illuminance levels. |
|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                       | **LUX (\* Klux)**    | 07/11 | 07/12 | 07/13 | 07/23 | 07/25 | 07/27 | 07/28 |
| Out Max*              | 106                 | 108   | 108   | 103   | 113   | 115   | 121   |
| Out Daily average*    | 83                  | 85    | 84    | 78    | 59    | 75    | 63    |
| Out Morning average*  | 79                  | 81    | 79    | 72    | 70    | 74    | 68    |
| Out Evening average*  | 88                  | 90    | 90    | 83    | 50    | 76    | 60    |
| Out Min*              | 35                  | 38    | 33    | 29    | 2     | 21    | 20    |
| A Max                 | 803                 | 742   | 890   | 624   | 646   | 794   | 563   |
| A Daily average       | 612                 | 560   | 631   | 414   | 382   | 342   | 318   |
| A Morning average     | 715                 | 660   | 764   | 407   | 413   | 493   | 377   |
| A Evening average     | 514                 | 464   | 502   | 419   | 354   | 194   | 264   |
| A Min                 | 283                 | 304   | 279   | 244   | 60    | 111   | 90    |
| Hours < 500           | 4                   | 4     | 3     | 9     | 9     | 8     | 9     |
| Hours < 350           | 0                   | 0     | 0     | 2     | 4     | 7     | 6     |
| B Max                 | 908                 | 774   | 1091  | 711   | 1364  | 436   | 489   |
| B Daily average       | 647                 | 578   | 644   | 397   | 465   | 281   | 269   |
| B Morning average     | 470                 | 444   | 486   | 441   | 477   | 295   | 203   |
| B Evening average     | 819                 | 707   | 795   | 358   | 460   | 267   | 333   |
| B Min                 | 226                 | 241   | 222   | 195   | 39    | 123   | 70    |
| Hours < 500           | 4                   | 4     | 4     | 9     | 7     | 10    | 10    |
| Hours < 350           | 0                   | 0     | 0     | 4     | 4     | 7     | 8     |
| C Max                 | 4040                | 4022  | 4065  | 2112  | 1336  | 4005  | 1406  |
| C Daily average       | 889                 | 894   | 915   | 383   | 281   | 636   | 258   |
| C Morning average     | 1008                | 1013  | 1010  | 354   | 369   | 858   | 270   |
| C Evening average     | 765                 | 771   | 814   | 409   | 196   | 413   | 246   |
| C Min                 | 229                 | 246   | 212   | 176   | 34    | 79    | 64    |
| Hours < 350           | 0                   | 1     | 0     | 8     | 9     | 7     | 9     |
| Hours < 250           | 0                   | 0     | 0     | 7     | 7     | 7     | 8     |
The spring/fall monitoring was carried out in March 2003. Six days were selected among those monitored. The windows were bleached during the 22nd and 23rd, the former day with little hazed sky and the second fully clear. During the 26th and 27th, the south-east window was dark in the morning and clear in the evening, opposing colouring was set for the south-west window, in both days the sky was clear. The windows were fully coloured during the 29th and the 30th, again with clear sky. The results are summarised in Table 2.

The results show the importance of using EC systems when the sun is low enough to penetrate into the test room, in fact the 500 lux are reached more frequently than in summer. In presence of direct sun (in the morning for A and in the afternoon for B), the windows are not dark enough to prevent for glare and further shading must be provided. In all the windows configurations, an illuminance higher than 2000 lux was registered for two hours a day, even if luminance measurements would be preferred for accuracy, this value testifies an excessive illuminance that the actual EC system cannot avoid. Without direct radiation, their performances improve, reducing the illuminance on the desk and mixing the glazing colouration with the window orientation can ensure good illuminance levels during the whole day. The zone C benefits of acceptable illuminance when the windows in the clear state or when they are alternatively coloured. If the windows are fully coloured, it is always required the use of artificial lighting. Excessive illuminance levels can be reached in the morning and in the evening.

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The winter monitoring was carried out in December 2002 and January 2003, but only the results of three days are presented. That period was, in fact, characterised by many cloudy and quick unpredictable days, which were unsuitable for the manual operation of electrochromic devices. The 19th and the 20th of December and the 6th of January were quite stable sunny days, even if the first day had an irradiation 20 to 30% higher than the other two. During the three days the windows were kept respectively: both coloured from 10am to 15pm, alternative coloured the south-east in the morning and the south-west in the evening, and both bleached. The illuminance values in the table refers to a monitoring schedule from 10am to 15pm, so it was only five hours a day.

This monitoring is characterised by high average illuminance, caused by the position of the sun. In fact the sunlight directly enters into the room, giving arise to very high peak followed by lower values in case of
diffuse daylighting, in table 2. In this case the analysis must take into account the hours higher than the two threshold values more than the average illuminance values. As already found for the fall season, the alternative colouring of the windows ensures a higher daylight availability and helps for glare prevention where it is needed. Position A and B can hence have a satisfactory natural lighting for several hours, position C suffers because of the colouring of the glazing, even if some daylighting can be provided without the use of artificial lighting. Colouring both windows make longer the time when the electric lighting is needed.

4. CHROMOGENIC GLAZING RESEARCH ACTIVITIES IN IEA – TASK 27

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. 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 (http://www.iea-shc-task27.org). 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, the daylighting analyses of test rooms equipped with smart glazing windows 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 2004.

The study here presented was carried on in the framework of this international co-operation project., together with the Italian research activities related to the Casa Intelligent project.

5. CONCLUSIONS

According to the achieved results some final conclusions can be summed up. It is important noting that it is not possible to extrapolate general conclusions from this study, because of the whole restraints typical of such analyses. One of these is the limited dimensions of the glazing surface, while best applications for electrochromics are in case of large glazed area, with all the negative and positive implications of the case. For more detailed daylighting analyses, beside illumine data, also luminance measurements ant contrast ratio should be taken for a correct evaluation of glare phenomena. It is finally important to perform further measurements with the automated control of the windows, in order to find out the best control strategies for such products.

Concerning the results of this experiment, because of the characteristics of the test room and the windows, during the summer season there is no risk of excessive illuminance on the working planes, except for short moments very close to the windows at sunrise and sunset. Under these conditions it seems that the best control strategies for the EC managements should be set according to thermal control and energy savings, even, if as showed above power consumption due to the artificial lighting should be taken into account.

The EC systems are useful to reduce the illuminance levels and to mitigate glare effects during the intermediate and winter seasons, when the low sun breaks deep into the room. In presence of direct sun the performance of commercial windows are not sufficient, but they are very useful in case of diffuse daylight with the clear sky, conditions that can last several hours a day. The colouring of both windows leads to low illuminance levels on the working desk facing the windows not in the sun and in the centre of the room, with consequent use of artificial lighting. The alternative colouring of the glazing gives better light distribution inside the room throughout the day with a limited need of artificial lighting. Control strategies of switchable glazings during the cold and intermediate seasons should be based on daylighting and glare comfort conditions as well.

A said before, the above notes are related to this experiment, with all the limitations of a case study. More full test bed analyses and researches are required in the field to get general conclusions on building integration of chromogenic glazing. This study can be considered as a preliminary contribute for future and more accurate researches in related to the use of smart glazing to improve the luminous environment of indoor spaces.

REFERENCES