Experimenting and testing the use of electrochromic windows in the Mediterranean climate.

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Keywords
1=Electrochromic windows
2= Architectural Envelope
3=Glass
4=Mediterranean climate

Abstract
The study on electrochromic glass, which was launched by the group several years ago, has already developed the first stage, the simulation of the use of such materials in a building with standard glass envelope, through appropriate computer modeling. The results were presented at GPD 2009 in an article entitled “Studying the performance of an electrochromic envelope in an office building in the Mediterranean climate”. The second part of the study is to test in order to verify the thermal characteristics of the electrochromic glass, such as building components, and the construction of a geometric model with a masonry envelope long-term use. The decision to implement a model designed for the survey, necessarily involves a preparatory step to the next phase of experimentation: an energy analysis of the model, through the software currently in use. The main goal is to have theoretical data to compare and verify against the real field test results and assess the reliability of the software used. The field test phase of the trial, which begins in the summer, will consist in setting up two test rooms of equal size, orientation and use. The electrochromic glazing will be implemented in one of the two rooms, while static conventional glass will be placed the other. Finally, instruments and sensors for measuring physical parameters of all the environmental gains in terms of energy will be localized in both rooms. The data collected will be processed periodically with specific software, and analyzed as a function of the primary goals of the research. This study will lead, in addition to verification of the results obtained through simulation, to evaluate the cost-benefit of using these windows. To found: a ratio between window areas and wall surface, medium or low, in buildings in the Mediterranean area. As a result, to fix the range identification of this ratio, in which the convenience of using EC windows becomes optimal.

1) Introduction – experiences and choices of the research team
The interest and the expectations that revolve around the present research on the changeable dynamic in colour window, expect fields of study that bring into play a relatively long time. This aspect adds to the need for operators to find physical environments to be tested, with the same geometric characteristics, orientation and use, available for the duration of the relevant studies and experiments. These requirements have guided the group’s choice on the implementation of a long-term use building and geometric model as independent of any context. This choice necessarily involves a preparatory step to the next phase of experimentation: an energy analysis model, through the software currently in use. The main goal is to have the theoretical data to compare and verify during the actual field test, to assess the reliability of the software used. For the sake of the immediate availability of the site, the location of the area has been identified in the roof of the building (Figure 1) where they can create the test rooms, which is currently one of the headquarters of the Department of Architecture at the Faculty of Engineering, University of Cagliari.

The implementation phase will begin in the summer, after the acquisition of the necessary permits in conjunction with a construction company in Cagliari that will supply the equipment and materials for the construction of the models. The two rooms will be then equipped with the tools for periodically detecting the hydrothermal parameters that will be developed to assess the energy performance of electrochromic windows, and to study comfort and the fading phenomena. This phase will be developed by the Department of Architecture in collaboration with the Department of Electrical Engineering and Electronics (DIEE) of the University of Cagliari.

The research team has developed for some time several investigations related to environmental comfort in relation to the study of electrochromic glass. Several studies on the subject, in addition to matters closely related to energy saving and the reduced environmental impact, have highlighted...
the benefits of living in a comfortable environment: psychological well-being, increased productivity, improved intellectual efficiency, and positive attitude. These factors are difficult to quantify in economic terms and are therefore not detectable in the cost-benefit analysis. However, it is believed that they should be necessarily highlighted in a comprehensive evaluation of the benefits produced by the use of dynamic variable color glass.

2) Brief notes on the electrochromic glass: composition and working

The EC glass is a transparent building component that can change its light transmission and absorption characteristics, when controlled by the user. The production system uses a vacuum sputtering (the process to that currently used to produce low-emissivity glass) process, to deposit a series of metal oxide based thin films on a sheet of transparent glass. The basic unit is then assembled into an insulating glass unit (IGU) just like Low-E coated glass today. The IGU is generally composed of (as shown in Figure 2 left): a transparent outer pane of tempered glass, on whose inner surface a multilayer electrochromic thin film is deposited, a second lite (inboard lite) of either laminated or tempered glass depending on the application. In addition to the EC coatings which also have Low-E properties, an additional Low-E coating can also be used on surface 3 to improve the insulating value yet further be added to the inboard lite. The dual pane unit can be constructed like any other dual pane unit, with for example different air spaced, worm edge spacer technology or argon filling. Currently, the combination of the EC glass technology in a triple-glazing (Figure 2 right) has led to a product with very high energy efficiency, greatly enhancing the already high performance of the dynamic double-layer glass.

The activation of a low voltage DC across the film produces a oxidation-reduction reaction in the EC active layer. This step induces a change in the ability of the EC layer to absorb light which causes the glass to change from highly transparent clear state to a highly tinted dark state (as shown in Figure 3), thus blocking 97% visible light and 99% of incoming solar radiation, significantly changing the value of the solar factor g (SHGC, Solar Heat Gain Coefficient), while maintaining the view and the connection to the outside.

The change takes place over a period of time ranging from three to five minutes, depending on the size of the glass and the temperature conditions. The activation of the transition state can be performed manually with the use of a simple wall switch, or through integration with an automated performance system.
building energy management system, using sensors, timers and more or both.

3) The test rooms: geometric and building aspects.

The test rooms, hereafter identified by the letters A and B, from a geometrical point of view, are represented by two identical volumes of 4 square meters in floor area, and a storey height of 2.70 meters, with a slightly angled roof. The size of the models and windows follows from the application of standards imposed by the municipal building regulations, which take into account the norms of hygiene and comfort for the design of all types of buildings.

The two rooms location is not influenced by the context on the terraced roof of the building host, so this fact suggested the orientation of the openings, on the south-east and south-west direction, to achieve maximum daylight exposure and optimal for the study of energy characteristics of a building in an area with a Mediterranean climate. The opening sizes are: for the window, 1.50 wide and 1.00 meters high, while the fully glazed door measures 0.80 wide and 2.10 meters high, with a ratio between total glass surface and total matt surface equal to 0.05.

From the construction point of view, two systems have been studied and set up for both the models of the simulation. The first is an envelope in which the vertical closures are made up of alveolar bricks hollow (Figure 5 left), with a high degree of thermal and acoustic insulation, 3cm thick, and a density of 700 Kg/mc, finished on both sides with a layer of thermal plaster, 3cm thick, and a density of 720 Kg/mc. The horizontal closures are assumed with a hollow block floor, total thickness of 24cm, completed with overlying functional layers, thermal, insulation, acoustic and waterproofing, for the total thickness of 30cm.

The second type is characterized by the construction system to a balloon frame. In this case, the vertical closure consists of a series of frames with glued laminated wood uprights, rectangular 16x6 cm, which serve as a support to the wall of the total thickness of 40cm (Figure 5 right) as follows, starting from the exterior: a layer of thermal plaster (5), 3cm thick with a density of 720 Kgm/mc, a panel of pine fibers oriented 6cm thick (6), a layer of basaltic rock wool insulation, 16cm thick and a density of 40 kg/m³ (7), two panels of pine wood fibers oriented thick 6cm each (8), a finishing coat of thermal plaster internal, 3cm thick with a density of 720 Kgm/mc (9). The composition is assumed for the horizontal top and bottom closures, which must be added to the functional layers to waterproof the roof and flooring for the lower level, which is raised about 15cm from the outside.

The two test rooms, used in two different simulations, identical in the size and construction type, differ only in the type of glazing assumed: A room has been glazed with the electrochromic insulating glass units (SageGlass®), mounted on a thermal break aluminium frame (Figure 6 point 8).

Starting from the outside, the electrochromic unit consists of a plate of tempered glass, 6mm thick (1), on whose inner surface is applied an electrochromic thin film multilayer (7), composed of oxides of metals, with characteristics of excellent durability and low-emission, a 90% Argon filled, 13.00 mm cavity(2), fabricated with a stainless steel spacer (5) hollow section (4) and sealed with a silicone-based compound (6). The inner surface is made of a laminated glass composed of two plates Planilux® Saint Gobain (11), each 3.0mm thick, between which there is a PVB film, 0.38mm thick (12).

4) The simulation: input data and results

The simulation was conducted with the help of the Autodesk® software: Ecotect Analysis 2010 version. The first step has seen the three-dimensional modelling and rendering of the two envelopes in the two rooms A and B, assumed with a load-bearing alveolar brick masonry construction.

In addition to the hourly and climate data of the locality of reference (hourly dry bulb temperature, hourly wet bulb temperature, hourly solar radiation) for the year 2010 the input data required by the software, relating to the characteristics of building components, synthesized and assembled in the following tables, namely, for the transparent surfaces, the same in both construction systems.
During the simulation, given the singularity of the test rooms, the limited size and no occupation by users, we have chosen not to define the heating and cooling system, so the software calculates the hours of comfort on the basis of inputs exclusively related to the envelope. Then several thermal analysis were extrapolated, and processed with graphics in order to show simultaneously, for comparison, the energy characteristics of the housing with the EC, and with the glass LE. Among the items obtained, the most significant emerging data are show in graphs (1, 2, and 3) relating to changes in the solar radiation, split into its fractions: incident, absorbed and transmitted during the day. It's calculated for the hottest day of the year: July 15, wrapped with a load-bearing masonry construction system. This choice is targeted and significant, as in the Mediterranean area the hot season is the most problematic in terms of the peak energy consumption to overcome the discomfort of the climate stress.

As you can see by the simultaneous analysis of our graphs, which shows the evolution of the incident fraction, the same in all three cases, changed from a minimum value of 14 W/m² detected at the 6.00 am, to a maximum value of 336 W/m² at 11.00 am, before falling back to the value of 44 W/m² detected at 14.00 pm. The absorbed part change is still interesting, it runs from a minimum value of 0 W/m² detected to 6.00 am, the same in three cases, to a maximum value of 37 W/m² at 11.00 am, for LE glass, 50 W/m² in the case of EC in the clear state and 21 W/m² for the active EC glass in its fully tinted state. There is a decrease to the minimum value of 0 W/m² at 14.00 pm, which remains the same in three cases. Remarkable is the oscillation curve of the transmitted fraction, which passes from a minimum value of 6 W/m² at 6.00 am for the LE windows, of 4 W/m² for the EC glazing (clearest state) and 0 W/m² for EC (fully tinted state), to a maximum value of 152 W/m² at 11.00 am for LE glass, 90 W/m² in the case of EC glass in the clearest state, 1 W/m² for EC in its fully tinted state, before easing to an other minimum of 20 W/m² at 14.00 pm, for LE glass, 13 W/m² for EC glass in the clear state and 0 W/m² for EC glass in the fully tinted state. If we translate these parameters in percentage terms it means, compared to the peak value at 11.00 am, there is a reduction of about 99% of the fraction of radiant energy transmitted between the case with the LE glass and the EC glass in its fully tinted state. The value diminishes, but it remains significant, at 35% between the LE glass and the EC glass in the highest transmission state, before rebounding to 98.9% in the comparison between the fully tinted and fully clear states of the EC glass. We can make the same remark as far as the fraction...
of absorbed radiant energy, even considering the maximum value. There is about a 46% difference between the LE glass and EC glass in the fully tinted state and about 58% between fully tinted and fully clear states of the EC glass. The analysis was also simulated in the same way for the whole year showing the maximum values relative to the fraction of incident radiant energy in August which stood at a value of 48.764 Wh/m², which remains constant for the three cases. Concerning the part of absorbed radiant energy, even in this case there is a peak value in August and specifically of 5.415 Wh/m² in the case of LE glass, of 7.332 Wh/m² in the case of EC glass in its fully clear state and of 3.011 Wh/m² for EC glass in its fully tinted state. Transmitted radiant energy, is 22.061 Wh/m² for the LE glass, 14.620 Wh/m² for the EC glass in the fully clear state and 13.320 Wh/m² for EC glass in the fully tinted state. Translating these parameters in percentage values we obtain the same situation before. The same simulations were conducted for rooms A and B, in the case of an envelope built with a balloon frame construction system, whose results are represented in the graphs (4;5;6).

The data obtained in this case may be regarded as comparable with the previous ones, as there is still a significant reduction in the value of the fraction of radiant energy transmitted through the electrochromic glass to the fully tinted state of around 99% (see Graph 6).

To complete the representation of simulation studies carried out, the following is the summary table with the percentages, relative to gains, collected over a year, intended as contributions due to several factors, namely: trade heat conduction through the envelope; indirect solar radiation, direct solar radiation, heat transfer by convection, internal inputs (lighting, equipment and users), thermal heat flow between adjacent zones.

These evaluations show the remarkable performance of the so-called smart windows in the energy field: the ability to dynamic and reversible change optical and thermal properties of the building envelope, according to the environmental conditions. It provides the ability to take advantage of free inputs of the solar radiation, when required or desired by the user, resulting in a significant savings in energy consumption for heating in winter and cooling in summer. Given that in Mediterranean countries, which are characterized by high temperatures in summer, the most energy consumption actually comes from cooling system, the use of dynamic variable tint windows represents the near future. On these bases, the next phase of the research will take place on the trial models built.
5) Conclusions

The analysis of our data from the simulation highlights and confirms the expected foresights as regards the energy performance related to the use of dynamic variable tint glass in the Mediterranean. They are able to achieve, together with other building components, an architectural envelope, in which environmental well-being and energy efficiency reach an optimal ratio. The simulation studied, on two different types of housing, has also made it possible to highlight an interesting item for discussion: the use and effectiveness of the electrochromic glass appears to be independent from the constructive system which makes up the volume. This element which features the versatility of electrochromic, can be of great importance because it allows you to extend the scope of their use to a wide range of building types, significantly broadening the energy savings. The transition to the next phase of experimentation with built models will test the reliability of the theoretical data obtained with the software. In this response a series of studies will follow related to the type of building and the relationship between opaque and glass surface, which will find a range of variation within which the use of EC windows is optimal. It is hoped also that the test data indicate the utility of the use of EC glass in the retrofit of existing buildings. All data will then be surveyed relative to the environmental comfort and energy savings on the entire envelope, considered in all its components, which is and remains the real goal of the research.

6) Acknowledgements

The research team wishes to thank the various partners that have made their contributions possible up to now, in the various steps and phases of the study in progress: Fondazione Banco di Sardegna; Electrochromics Inc. Faribault, Minnesota (USA); Laborvetro Srl, Cagliari (Italia); Ziro Immobiliare Srl, Cagliari (Italia).

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<table>
<thead>
<tr>
<th>GAINS</th>
<th>CONDUCTION %</th>
<th>SOLAR INDIRECT %</th>
<th>SOLAR DIRECT %</th>
<th>CONVECTION %</th>
<th>INTERNAL %</th>
<th>INTERNAL ZONE %</th>
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<tbody>
<tr>
<td>LE GLASS</td>
<td>0,7</td>
<td>6,5</td>
<td>18,4</td>
<td>2,9</td>
<td>70,7</td>
<td>0,7</td>
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<tr>
<td>EC GLASS (clear state)</td>
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<td>7,0</td>
<td>12,7</td>
<td>3,1</td>
<td>75,6</td>
<td>0,8</td>
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<tr>
<td>EC GLASS (fully tinted state)</td>
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<td>8,0</td>
<td>0,1</td>
<td>3,6</td>
<td>86,4</td>
<td>0,9</td>
</tr>
</tbody>
</table>

Table 4 Gains due to: the heat conduction; the indirect solar radiation; the direct solar radiation; heat transfer by convection; internal inputs; thermal heat flow between zones.