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Architectural evaluation of switchable glazing technologies as sun protection measure

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Abstract

Switchable glazing technologies seem to be a promising component of solar buildings. Switchable glazing may controllably and invertably change its physical and visual properties by switching. Having been applied in buildings envelopes, the switchable glazing technologies are frequently regarded as an alternative measure for traditional solar protection elements like: blinds, louvres, overhangs etc. Yet, they are more integrated with buildings envelope creating kind of interactive barrier between external and internal environment. They also provide sleek and changeable glazed envelopes, thus becoming an important element of buildings architecture, too.

The glass technologies to be considered in the paper are: SPD (suspended particle devices) LCD (liquid crystal devices), EC (electrochromic), GC (gasochromic) and micro-blinds technology.

The paper concentrates on architectural evaluation of the application of the switchable glazing technologies as sun protection measures. They are examined in context of their influence on thermal and visual comfort first of all. Besides, aesthetical and energy –efficiency issues have been discussed.

The paper is aimed at showing opportunities connected with application of the different switchable glazing technologies according to their impact on architecture. To this aim a comparative method has been used. The technologies were compared with each other on the following fields : thermal protection, lighting protection, visual contact, aesthetic variability, electricity consumption.

It has been proved that the above mentioned technologies exert different impact on internal environment of the building and its architecture. They are relevant for different tasks - e.g. some of them are especially suitable for thermal protection, whereas the others should be used as visual control measure first of all. All of the technologies may be used both in hot and cold climates, but the way they should be used in the buildings envelope (e.g. place, solar orientation) are different.

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Keywords: switchable glazing, switchable technology, solar architecture, low-energy architecture

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1. Introduction

Switchable glazing technologies seem to be a promising component of solar buildings. Switchable glazing may controllably and invertably change its physical and visual properties by switching.

Having been applied in buildings envelopes, the switchable glazing technologies are frequently regarded as an alternative measure for traditional solar protection elements like: blinds, louvres, overhangs etc. Yet, they are more integrated with buildings envelope creating kind of interactive barrier between external and internal environment. They also provide sleek and changeable glazed envelopes, thus becoming an important element of buildings architecture, too.

The glass technologies to be considered in the paper are: SPD (suspended particle devices) LCD (liquid crystal devices), EC (electrochromic), GC (gascochromic) and micro-blinds technology.

The paper concentrates on architectural evaluation of the application of the switchable glazing technologies as sun protection measures. They are examined in context of their influence on thermal and visual comfort first of all. Besides, aesthetic and energy–efficiency issues have been discussed.

2. Presentation of switchable glazing technologies

2.1. SPD (suspended particle devices) glazing

Transparent glass becomes translucent or opaque. Between two layers of glazing there is suspension of freely arranged particles. In the off position the particles are randomly oriented and the glazing absorbs solar energy. When a voltage is applied, the particles align with the electric field and the glazing becomes clear increasing radiation transmission.

Fig.1. Schematic view of the SPD glass section [author]

2.2. LCD (liquid crystal devices) glazing

Transparent glass becomes opaque. Between two layers of glazing there is a film of liquid crystals. When no voltage is applied the liquid crystal molecule chains are randomly scattered and the glazing becomes translucent opal white. The molecules align with the line after voltage is applied and the glass becomes transparent.

Fig.2. Schematic view of the LCD glass section [author]
2.3 EC (electrochromic) glazing

Transparent glass becomes colored. It consists of two layers of transparent conductors, electrolyte, electrochromic layer (active layer) and ion storage layer (passive layer). The glass state transition is due to movement of ions influenced by voltage. The outflow of ions out of the electrochromic layer makes the glazing darken. By reversing the direction of electric field, ions return to electrochromic layer and the glazing becomes clear again.

![Fig.3. Schematic view of the EC glass section](image)

2.4 GC (gasochromic) glazing

Like in EC glazing, transparent glass becomes colored; colour change takes place by means of gas mixture. Diluted hydrogen flowing through the void between two layers of glass react with gasochromic layer and makes the glass colored. In turn, by adding some quantities of oxygen concentrations, the color disappears.

![Fig.4. Schematic view of the GC glass section](image)

2.5 Micro-blinds glazing

Transparent glass becomes translucent or opaque. The surface of glass is coated with a layer of micro-blinds in the form of metal film. The micro-blinds are of micrometer size that makes them practically invisible to the eye. They are curling electrodes activated by voltage. When the voltage is applied, the micro-blinds function like a screen reflecting solar radiation to the outside.

![Fig.5. Schematic view of the micro-blinds glass section](image)
3. **Comparison of the switchable glazing features**

3.1. **Thermal protection.**

Thermal protection of the glazing technologies as solar protection measures may be defined by solar heat gain coefficient (SHGC or g).

All of the technologies considered, apart from LCD technology, have an impact on reduction of total solar energy transmission in their activated state. LCD panels cannot control heat flow through the glazing. They do not actually exhibit variable transmission characteristics, since they only affect the way light is transferred and not the quantity of radiation that is allowed to pass through [6].

In all technologies, except micro-blinds windows, switching occurs through absorption. The micro-blinds technology prevents overheating by reflection.

On the basis of the most referenced sources, one can estimate typical g-values for the technologies presented. The values are shown in table 1.

<table>
<thead>
<tr>
<th>g-value</th>
<th>SPD</th>
<th>LCD</th>
<th>EC</th>
<th>GC</th>
<th>Micro-blinds</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear</td>
<td>0.50-0.70</td>
<td>-</td>
<td>0.50-0.60</td>
<td>0.75</td>
<td>lack of comparable data</td>
</tr>
<tr>
<td>darken</td>
<td>0.41-0.56</td>
<td>-</td>
<td>0.05-0.30</td>
<td>0.14</td>
<td>lack of comparable data</td>
</tr>
</tbody>
</table>

The switching time is the shortest in case of micro-blinds technology. It is rapid and counted in milliseconds. The transition of SPD glazing is also immediate (less than a second). LCD glass changes its state within several seconds. In the case of GC switching speeds are 20 seconds to color and less than a minute to bleach, and in EC technology typically full coloration is achieved in 5-10 minutes.

![Fig.6. Physical behavior of the switchable glazing technologies in context of their total solar energy transmission properties](image-url)
3.2. Lighting protection.

Comparison of switchable glazing technologies as solar protection measure should be accompanied by lighting protection analysis. In this field, glass properties may be measured by visible transmittance factor (Tv).

All of the technologies considered, except LCD glazing, noticeably change their Tv values according to their state. LCD technology, as already mentioned, do not affect the way the solar radiation is transferred. Its influence is negligible.

On the basis of the most referenced sources, one can estimate typical Tv values for the technologies presented. The values are shown in table 2.

<table>
<thead>
<tr>
<th>Tv (%)</th>
<th>SPD</th>
<th>LCD</th>
<th>EC</th>
<th>GC</th>
<th>Micro-blinds</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear</td>
<td>22-57</td>
<td>77</td>
<td>50-70</td>
<td>59-75</td>
<td>65</td>
</tr>
<tr>
<td>darken</td>
<td>5-20</td>
<td>76</td>
<td>2-25</td>
<td>10-18</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig.7. Physical behavior of the switchable glazing technologies in context of their light transmission properties [author]

3.3. Visual contact.

There are noticeable differences in terms of visual contact behavior among switchable glazing technologies. They may be characterized in two groups.

In EC and GC technologies, the effect is that the glazing switches between a clear and transparent or semi-transparent tinted state with no degradation in view [2]. They can be modulated to any intermediate state between clear and fully colored but provide visual contact across their switching range.

Suspended particle and micro-blinds device windows provide obstructed view when darkened. They can also be opaque, functioning as a “view shield”. This ability is also typical for LCD glazing, which has
usually only two states, clear and diffusing. SPD and micro-blinds glazing, as well as EC and GC devices, may reach intermediate states. All technologies provide visual contact in their clear state, nevertheless one can observe a slight haze or scattering. Also EC windows are slightly yellowish.

3.4. Aesthetical variability.

SPD glazing typically changes its color to dark (cobalt) blue. However new suspensions are also under development to achieve several different colors (green, red and purple). The tint may be varied depending on how much current is applied and the change is almost instant. EC glazing when activated becomes blue (Prussian blue) [2], as does GC glazing, although their shades vary one from the other. Moreover EC glass may be produced in dark brown and black colors. For the both technologies, the intensity of colors changes along with transition process from one state to another.

LCD glazing is originally opal white in its opaque state, but some manufacturers offer products in a variety of colors and graphics including dynamic displays (both on curved and flat-shaped glass) [2]. The micro-blinds are like micro-mechanical shutters, so there is no limit in their coloration. Tint could be added upon request.

3.5. Electricity consumption.

SPD device requires typically 50-100 V AC to operate from the colored (off) state to the near transparent (on) state. Depending on the amount of voltage it can be modulated to any intermediate state. Power requirements are ~5 W/m² for both switching and to maintain a constant transmission state. [2], but it is expected to get down to 1W/m² [8]. The same power (~5 W/m²) is required for LCD glazing to remain in the clear state. The glazing operates between 24-100 V AC [2]. Devices remain transparent only for as long as the electric field is maintained [6].

In contrast to SPD and LCD technology, the EC and GC windows require typically small amount or none of power respectively. EC glazing requires low-voltage power up to 10 V DC to change their state. For some EC types (polymer laminate), the device is switched to its desired state and then no power is needed to maintain the state. This type of device has a long memory once switched (power is not required for three to five days to maintain a given switched state) [2]. When no voltage is applied, EC glass remain in the clear (off) state.

The GC windows are not powered by electricity. The switching process is stimulated by gas (hydrogen/oxygen) that can be generated at the window wall with an electrolyzer and a distribution system integrated into the façade.

In case of micro-blinds technology, actuation voltages 20-30 V have been observed, but typically one can assume range of 30-50V as an operational voltage. In case of power failure, the rolling electrodes (micro-blinds) would go in open state. It is expected to achieve low power consumption of approximately 1W/m² [8].

4. Architectural evaluation – discussion

4.1 Thermal comfort.
All the technologies, apart from LCD glazing, affect thermal comfort by reduction of solar rays transmission and thus preventing overheating due to greenhouse effect.

SPD, EC and GC technologies act as a solar barrier by absorbing solar energy. This makes that they should be used in insulated glass units (DGU or TGU) to unable solar heat transmission from the window pane to the interior.

Relatively low g-values of EC glazing in a colored state makes it especially proper for the application in hot climates, where solar heat protection is a priority. It is also suitable in colder climates within roofs and elevations which are unfavorably exposed to the solar rays operation during hot periods. This refers particularly to the glazed facades and windows oriented to the east and west.

GC glazing with its a bit higher g-value may also play a significant role of solar protection as mentioned above, however the values suggest that it is more relevant for application in buildings where passive solar gains are expected. Consequently, in comparison with EC glazing, GC technology usage seems to be slightly more reasonable in colder climates where there is a need of both solar protection as well as solar energy use in hot and cold periods respectively.

SPD glazing is regarded as a bit poorer solar protection measure [1],[6],[11], although it can play this role as well.

An advantageous feature of EC and GC glazing is their relatively high g-value range (from clear to darkened state), so one can conclude, that the glazing is better adopted to changeable climatic conditions than SPD glass. On the other hand, shorter switching time of SPD glass is favorable in case of dynamically changing weather conditions (intensity of solar operation) during a day.

In case of micro-blind technology, due to lack of comparable studies, it is hard to evaluate it as a solar heat protection measure. However, because of its ability to reflect solar rays, the technology seems to be promising in this field. First measures for DGU indicate g-value on 10-50, so one can assume similar abilities to EC glazing. The shortest switching time can be regarded as follows.

4.2. Visual comfort.

Visual comfort may be considered in two problematic fields: privacy /contact view provision and solar light transmission control.

Liquid crystal windows are best suited for privacy control as they act as a view barrier in their off state, but they almost do not affect light transmission level. Good privacy control is also a domain of SPD technology. In this sense, SPD may be perceived as an alternative to LCD, but their primary advantage over liquid crystals is their ability to permit much more oblique viewing [1]. Change in tint is instant and a user advantage to this technology is that the voltage can be varied to give a different level of tint and therefore the transmission properties can be changed to suit any particular external environment (Cambridge). This applies also to micro-blinds technology, but the main difference is that it remains transparent when not activated.

In the contrary, GC, EC allow to remain contact view in their totally darken (on) state whilst provide significant solar light transmission control. However one cannot see a totally unscattered view. In the off state, the glazing is transparent, but in case of EC some users complain about irritating yellowish tint. The additional difference between GC and EC technologies is higher value of Tv in bleached state of the first one. This means that GC is slightly more proper for applications where there is a special need of natural light use (e.g. most of the office and residential buildings). In the darken state, the EC and GC glass become typically navy blue whilst provide contact view to the outside. The picture perceived by the user looking through the window is slightly unnatural in tint, but according to research, the fact is acceptable by 2/3 of users [14]. The windows change also the tint of solar light passing through to the room. This makes them irrelevant for buildings, like e.g. some museums and laboratories, where a color of light plays a significant role.
Another important issue is a switching time. Short switching time, in case of micro-blinds and SPD glass, means immediate solar light protection, which is particularly helpful where protection against sudden glare may be needed (e.g. offices directly situated by windows with eastern and western orientation). In turn, long switching process (GC and especially EC technology) allows for adaptation of the eye to changing light intensity level and its tint.

To conclude, LCD and SPD are especially appropriate for applications where privacy of users is required and where visual contact with the surroundings is not a priority. Thus they are not relevant when both viewing and solar control (heat and light) is needed at the same time. Micro-blinds technology is some kind of intermediate solution between SPD/LCD and EC/GC. On the one hand it acts as a traditional solar window in its off state (like GC/EC glass), but on the other hand, when activated, it cuts viewing, like SPD and LCD technology. Besides it provides significant solar light protection.

The main advantage of EC and GC technologies are their functional merits. They can exert impact on lighting environment by regulation of solar light transmission level, whilst remaining the major role of the window visibility to outside.

### 4.3. Aesthetics.

The issue may be considered in context of the influence of the switchable glazing technologies on buildings aesthetics, such as its façade. One of the most important issues is appearance of the glazing in its darkened state and potential of the artistic creativity.

The biggest potential represents LCD technology which, as already mentioned, may be produced not only in different colors, but also enables introduction of variable graphics and dynamic displays. A building’s façade may become a large-area screen with unlimited artistic effects. Micro-blinds technology is also promising, as the shutters may be produced in different colors. As it is not commercialized yet, one cannot judge its aesthetical influence unequivocally, but one can expect it will be willingly used as an artistic tool by the architects in the future. The relatively modest palette of colors of SPD, EC and GC glazing limit their influence on aesthetics of the façade.

Another drawback of the SPD and EC glazing is size limitation. However, along with LCD, as the most advanced commercially technologies, they are offered in different shapes on the building market. All the technologies represent satisfactory level of coloristic homogeneity. Their undeniable advantage is ability to change their visual properties that consequently influences the building’s façades, making them perform like a dynamic “living skin”.

### 4.4. Energy efficiency.

LCD and SPD device windows are in the group of electrically activated smart windows in which clear state is achieved when an electric current is continuously applied. In this sense, they are relatively energy-consuming, unless they are used in buildings where privacy control is a priority (remain in off state for a long time).

Liquid crystal windows do not provide energy savings as they cannot control transmitted solar radiation. SPD glazing, in contrast to LCD, is able to respond to desired outcomes, which are reduction of solar light and heat intensity. For this reason it may be treated as an element of energy-conscious buildings, exerting impact on reduction of HVAC systems. Nevertheless, relatively low value of T factor means reduced amount of natural light and thus increased use of energy consuming artificial illumination.

EC and GC windows are more proper for energy-efficient buildings due to cause reduction in transmitted radiation while remain transparent. They need less energy to function and provide more natural light than SPD windows in their bleached state. Research proves that EC and GC glazing may be almost twice as energy-efficient than traditional solar glass [14].
GC glazing, as said before, is most suitable for passive solar concepts. In case of micro-blinds windows, the fact that they are reflective makes them a very good thermal barrier in closed state and thus an important element of passive solar cooling. Small amount of energy consumption and relatively high value of $T_v$ factor in clear state are also advantages, but the technology needs more research on the field of energy efficiency.

### 5. Summation

All of the technologies, apart from LCD, may be used as a solar shading measure. Anyway they exert different impact on internal environment of the building and its architecture. They are relevant for different tasks. They may be used both in hot and cold climates, but the way they should be used in the buildings envelope (solar orientation, internal space characteristics etc.) are different.

Tab. 3. Architectural evaluation of the switchable glazing technologies use (underlined words mean particularly suitable) [author]

<table>
<thead>
<tr>
<th>Climate</th>
<th>SPD</th>
<th>LCD</th>
<th>EC</th>
<th>GC</th>
<th>micro-blinds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>warm</td>
<td>-</td>
<td>warm</td>
<td>warm</td>
<td>warm</td>
</tr>
<tr>
<td>Climate</td>
<td>cold/intermediate</td>
<td></td>
<td>cold/intermediate</td>
<td>cold/intermediate</td>
<td>cold/intermediate</td>
</tr>
<tr>
<td>Characteristic weather conditions (micro-climate)</td>
<td>many sunny hours, dynamic insolation changes, supremacy of high external temperatures</td>
<td>-</td>
<td>many sunny hours, stable insolation conditions, supremacy of high external temperatures</td>
<td>many sunny hours, constant insulation conditions, relatively large number of cold days-passive solar heating required</td>
<td>many sunny hours, dynamic insolation changes</td>
</tr>
<tr>
<td>Main role</td>
<td>solar lighting protection, solar heat protection, privacy control</td>
<td>privacy control</td>
<td>solar heat protection, solar lighting protection</td>
<td>solar heat protection, solar lighting protection</td>
<td>solar lighting protection, solar heat protection (expected), privacy control</td>
</tr>
<tr>
<td>Main role</td>
<td>windows, glazed walls, skylights (e.g. as a “display screen”)</td>
<td>glazed walls skylights</td>
<td>windows, glazed walls, skylights</td>
<td>windows, glazed walls, skylights</td>
<td>windows, glazed walls, skylights</td>
</tr>
<tr>
<td>Orientation (in northern hemisphere)</td>
<td>east, south, west</td>
<td>-</td>
<td>east, south, west</td>
<td>east, south, west</td>
<td>east, south, west</td>
</tr>
<tr>
<td>Appropriate internal space characteristics (space neighboring with external walls/roof)</td>
<td>space with privacy demand coupled with solar lighting control, 1. no special needs of high-quality natural lighting provision</td>
<td>space with natural lighting demand coupled with privacy control</td>
<td>space with contact view needs coupled with solar heat and lighting control, space with natural lighting demand (high quality not required)</td>
<td>space with contact view needs coupled with solar heat and lighting control, space with natural lighting demand, space acting as a passive solar collector</td>
<td>space with privacy demand coupled with solar heat and lighting control, space with natural lighting demand, no special needs of high-quality natural lighting and contact view provision</td>
</tr>
<tr>
<td>Aesthetic potential</td>
<td>medium</td>
<td>very high</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Energy-savings potential</td>
<td>medium</td>
<td>-</td>
<td>high</td>
<td>very high</td>
<td>high (expected)</td>
</tr>
</tbody>
</table>
6. Conclusions

Successful implementation of the switchable glazing technologies means finding a compromise between solar heat protection and architectural and functional demands. Maximal heat protection results in decreased daylight level and solar energy transmission. On the other hand, maximally transmitting glazing reduces thermal comfort. Therefore a design of transparent façades has always to reflect the needs of the users and respond to distinguishing requirements of the buildings.

For this reason the technologies as yet cannot be regarded as a completely satisfactory solution in providing solar protection and natural light, privacy control, contact view at the same time. They should be coupled with other solar or thermal protection elements, like external shading elements and insulating glazing units mainly.

Nevertheless switchable glazing technologies may substantially contribute in improving thermal and visual comfort while reducing energy consumption of the building. This results in economic and ecological profits. The important issue is also aesthetics. The visual changeability may be perceived as a powerful “tool” in creation of expressive modern architecture dynamically responding to the environmental changing conditions.

References