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Smart building materials in sustainable architecture: A case study in Electrochromic glass

Mahdi Tarfiei
Faculty Member of Department of Architecture, Neyriz Branch, Islamic Azad University, Neyriz, Iran

Abstract

Applying smart building materials in addition to be more compatible with the surrounding environment, meet the users' need with higher quality and also reduce environmental problems. In recent decades and following dramatic scientific progresses as well as new approaches in sustainable architecture this type of materials have been proposed. Smart materials have opened a new opening to the architects and builders and removed many restrictions. Smart glass are the smart materials that permit the controlled light and heat get transmitted into the building and remove some traditional restrictions in applying windows. In this study, after investigating electrochromic glass as one of the smart glass, their application in the smart sustainable buildings are shown with some case studies. The approach of the study is descriptive–analytical and reliable documents of library were used in it. the results of the study confirmed that using smart materials cannot lead us to the objectives proposed in sustainable architecture but smart apllication of a colloction of materials and architectural facilities appropriate to the needs of the project form ideal results. Since this issue is new in Iran, the neccessity on conducting these kind of studies in order to identify various technical and executive aspects as well as the equipment provided for the architects and builders is confirmed.

Keywords: Chabot College (CSSC), electrochromic glass, smart glass, research support facility (RSF), smart building materials, sustainable architecture

Introduction

Since long time ago, humans have been inspired by natural forms to build, and the nature have always been used as inspiration for ideas and comments on the design and engineering subjects. Living creatures have features such as motion, variability, adaptation, response to external stimuli and so on. These creatures are as smart systems, because their construction materials, in addition to working with each other, react to external stimuli sets. Since the beginning of the 1980s, the scope of the design and construction of buildings have been run into new innovations in the field of more effective and more efficient materials. In the direction of progress, the materials capabilities have been added day-to-day and Humans have always been introduced the introduction of new materials in the field of construction. Today, the buildings are kind of technology that is constantly reacting to the changing situation of the environment and adapt themselves with them and take advantage of them. Undoubtedly, the use of such materials adds the service life of the building and as a result, dramatically reduces the cost of building maintenance (Golabchi, and Taghizadeh, 2011).

At present, a wide range of products and materials have been available or that are introducing to the market. Some of them are specifically produced to be used in architecture and some others are regarded for other applications such as textile industry, automotive. But the main point is how to make the new materials available to architects and designers? If the architects are provided the possibility to apply all the materials and products directly or in the form of modified in their projects, then a huge amount of new and interesting equipment and materials will be followed to design buildings and construction m ethods. Creative architects can develop new materials and products for special architectural applications and will be able to create a new industry in

architecture based on new materials. As a result, architects will be entrepreneur, producer and builder of the buildings instead of being the designer of the buildings (Addington, Michelle, and Daniel, 2005).

Today, with the foresight view to the architecture and construction systems by architects, the development of smart materials in the field of architecture in the country will be soon observed. Therefore, knowing and understanding the characteristics of the materials and their applications in today's world is inevitable (Gorji Mahlabani, Haj Abutaleb, 2009).

Given that the experience of applying smart materials in buildings is new in Iran, conducting studies to understand and learn the rules and principles governing this area and the facilities which are provided seems necessary.

Smartness

Smart, intelligent, sensitive and adaptive all are used to define the structure and materials including sensors and actuators, and are able to adapt to external stimuli such as bars and environmental stimuli (Jahans, 2007). Smart architecture is dynamic which means it changes its main performance parameters according to need, demand and changing and dynamic conditions. A smart architecture like a living system is capable to accumulate and use experiences in the new conditions and with the characteristics the systems's dynamics and self-organizing will be guaranteed. The main charectristics of smart architecture are as follow:

- Being active and dynamic;
- Being flexibale and consistent with the environment;
- Being responsive and reactive (Mofidi and Roshan Zamir, 2009; Armaghan and Servatju, 2011).

Smart materials

smart materials is a new term for materials and products that have the ability to understand and process environmental events and react appropriately to it. In other words, these materials have the capability of variability and are able to change their shape, form, color and inner energy reversibly in response to physical or chemical effects of the surrounding environment. If material are classified into three groups of non-smart, semi-smart and smart materials, the first group, non-smart materials, do not have the above specific charactristics; semi-smart materialsare only able to change their form and shape once or twice in response to the environmental effects; but in smart materials theses changes are repeatable and reversible (Ritter, 2007).

Smart materials with the chromic capability

One of the most interesting groups of smart materials that are also more considered, are materials with the chromic capability. This material can be divided in the following categories:

Table 1: Classifying materials and with chromic capability (Baghestani, 2013; Bazr Afkan and Beigi, 2009)

No.	Type of smart materials	Output energy	Input energy
1	Thermochromic	Color Change	Temperature change
2	Photochromic	Color Change	Light Change
3	Electrochromic	Color Change	Voltage change
4	Liquid crystal	Color Change	Differences in Electrical current
5	Camo chromic	Color Change	Specific chemical conditions
6	Mechanochromic	Color Change	Pressure or deformation

Material / Electrochromic Glass

Electrochromic materials change color or transparency using Electrical current (such as liquid crystals). Perhaps the materials are the most suitable materials to control the energy in buildings. The glass made by these materials quickly change from transparency into glumy and disperse the light. Their first performance is to crearte privacy and daze (Golabchi, and Taghizadeh, 2011). Similarly, smart electrochromic glass (EC) creates different output radiant energy by using low voltage Electrical pulse and by pushing a switch changes in them from light to dark or any degree of color occurs across the spectrum (Granqvist, et al. 1998). This type of glass is widely used to reduce heat transmision (Mahdavinejad, et al. 2011). In this glass, the unit of glass using transparent film with a thickness of 200 to 300 nm in the visible spectrum with different color intensities vary from clear to dark blue.The unit of glass is connected to Electrical power in order to change the value of ideal transpsrency according to different values of heat transmision. After the cutout, the changes of optical mode is maintained and a steady flow of Electrical ity is not needed. When the glass color goes dark thermal radiation is reduced and more passing radiation is filtered in the infrared spectrum. Energy consumption for a full cycle is less than 0.5 watt hours per square meter and this continuous and quiet trend is done for 15 minutes for the biggest size of the cup (2 × 1.2) m (Jahans, 2007).

Features of Electrochromic Glass

- Electrical current creates a chemical reaction that causes the glass to be colored;
- Depends on Electrical current, the dark color chosen for the glass provides the possibility to have more control the intensity of sunlight;

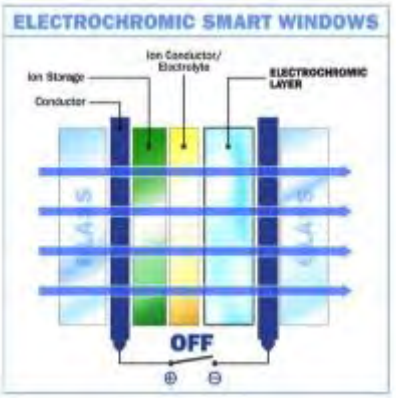

Figure 1: The layers of electrochromic window

- Electrical current is just needed to change the color mode and is not needed to maintain the value of the color;
- Very small Electrical current is required (Electrical energy required for electrochromic windows of a building is equal to the energy used by a light bulb).

Mechanism of action of materials / electrochromic glass

When the sunlight shines on the glass, electrical current is generated and causes the ions to move from the ion storage layer to the ionic conductivity layer and returns to the electrochromic layer and makes the glass dark. With electricity cutoff the process acts the opposite and the glass goes to transparent again (Mazdab, 2002). Electrochromic window is a window with an electrochromic layer that can electronically control the amount of heat and light passing so that on hot and sunny days by making it dark, the intense of light and heat entering the building is reduced

and on cold days by making it transparent the sunlight is allowed to get into the building. Therefore in addition to reducing energy demand in buildings, The need for curtains for the windows is resolved and the user can apply a constant voltage to change the color of the electrochromic window from light blue (transparent) to dark blue (dark) and in this way, brightness, sunlight and the passing heat can be controlled (Sedigh Ziabari, 2010).

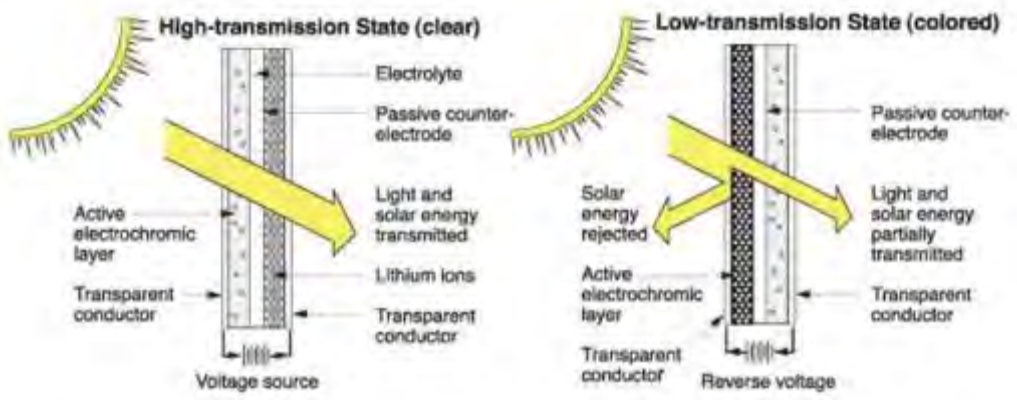

Figure 2: The effect of light in the case of electrochromic glass
Right: low light (colored glass) / left: high light (colorless glass)

Description of Figure 2: Schematic diagram consists of a five-layer electrochromic coating (without scale- true thickness of four microns, or one fifth of a human hair).

A renewable source of low voltage, makes the ions move forward and backward between active electrochromic layer and diactive counter electrode. When the lithium ions migrate to active electrochromic layer, electrochemical reaction makes the layer dark. When the voltage gets reversed and the ions return to the first place, electrochromic layer returns to the colorless state.

Field test of the electrochromic window

In Figure 3, left side, visibility to the electrochromic window can be seen from the interior space. The right column of this window is set to full white or colorless and the left column of the window is set to full color. The middle column of windows is set for light transmission between two Full mode. As can be seen, electrochromic window can change its color according to the intensity of sunlight using a voltage change and the amount of light in space with respect to the of this issue is different. The more voltage is applied the darker the glass will be and less light enters the space.

Figure 3: Field test of the electrochromic window
Right: Visibility from the outside / left: Visibility from inside

Case studies

Chabot College Community and Student Services Center (CSSC)

Chabot College Community and Student Services Center has nearly 15,000 students, staff and faculty members. The design of the College is based on the use of sustainable architecture strategies that include: atrium that optimizes daylight and energy efficiency, using electrochromic smart glass and radiation from the floor as heating and cooling and natural ventilation. The atrium of the set consists of a curtain wall with an area of 2900 square feet on the southern and western fronts that creates an unobstructed view to the courtyard and directs natural light deep into the inside and reduces the need for artificial light. Atrium orientation according to the the glaring sunlight and sun's too much heat is challenging because it must simultaneously provide visibility to the outside and thermal comfort for residents of the building. To meet this challenge, the smart layers were used for Atrium by the team. Electrochromic layer system will be automatically colored during the day to control the glaring radiation and heat of the sun obtained through curtain walls of the atrium. The system has created six integrated automatic six areas in the management of the building environment. Glass based on pre-defined threshold temperature in every area, is changed from the dark to the the light. Heating and cooling from floor and natural ventilation control air temperature in the environment. Electrochromic layer adjusts air flow through especial ventilation scopes in the roof and and radiation panels for heating and cooling of the air. As the air getting into the building through the roof of the building, the amount of heat transfering through the glass is connected with cooling or heating that creates air flow in the Atrium space through radiant panels. According to the a pre-defined threshold temperature of each of the areas, air gets warm or cooled through radiant thermal panels and then let them get out of the building through the air conditioning ducts without using the scope. Due to the unique ventilation system and windows with colored smart glass, air conditioners are not needed to help reduce energy and costs in atrium.

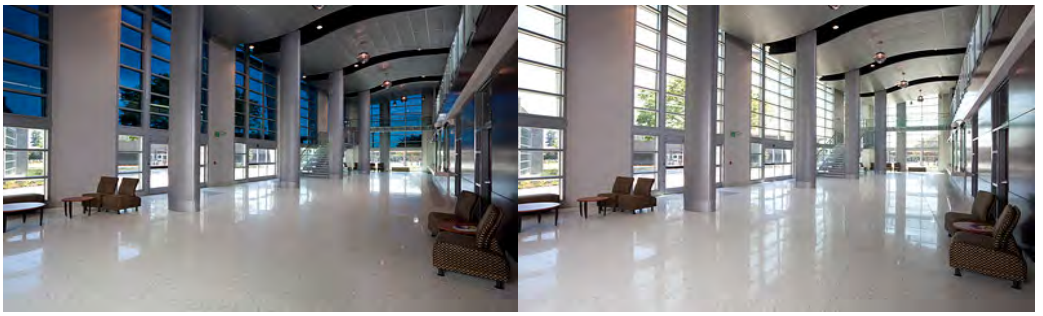

Figure 4: The Visibility from inside the Atrium of Chabot College

Description of Figure: The right side shows electrochromic layer in a colorless state to allow much light to get in and the left side shows the layer in color state and low light entering into the building.

Research Support Facility (RSF)

Research Support Facility is located at the National Renewable Energy Laboratory (NREL) in Golden, Colorado America in an area of major research and development and is one of the few facilities built for energy efficiency and renewable energies in this laboratory so that it can become a model for energy sustainability. Each of these buildings have been constructed in order to achieve the standard of United States of America in the field of energy developed by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED). Daylight is one of the key stimula in the design of Research Support Facility in terms of energy efficiency in America and that is why building is relatively narrow and long from front to back. Daylight and sun enrgy form

the main core of the building and windows are tools to direct light into the building. In order to get the maximum energy into the building, designers checked the size and composition of glass used in windows so that it can increase the amount of light and reduce glare and light intensity and prevent the entry and exit of unnecessary heat in buildings.

Sustainable design approaches in research support facility (RSF)

Finally, based on the principles of sustainable architecture design team used the following measures:

Northern windows should be slightly larger and with more height than their southern windows because sunshine is softer and more sporadic in north front, yet almost indirect. To help strengthen the penetration of light to the spaces, some of the windows have awnings shutters on the inside of window. These awnings shutters are like a small horizontal windshield blind hung upside down from the top of the window. The curvature of shutters was so carefully designed that it could grab light and throw it deep into the building and increase the deep of light entering the building from 20 feet to 30 feet. Given that windows have a dual and contradictory nature on the case of light getting into the building and lossing energy in it, it was solved by the use of new technologies. For this purpose, at the end of the two wings of the building, two types of smart glass, electrochromic and thermochromic have been used to ensure energy savings. Given that the thermal load is available on the west side of the building because of direct radiation even in the winter, electrochromic glass was used. When an electric current is applied on electrochromic glass it gets colored and in this case the possibility to control solar radiation entering the environment is provided by reducing the solar spectrum. These type of glass reduces thermal load, particularly during heat peak in which cooling the building contains the highest costs. Electrochromic glass is under the user's command because of their features in becoming dark by applying voltage, they can be connected to an integrated control system in the building making decisions when the building gets dark.

Identifying the components of Research Support facility (RSF) related to sustainable architecture

With the help of figure 5, the features used in sustainable design of different components of Research Support facility that leads to optimizing the use of renewable energy and to improve energy efficiency are explained below:

Figure 5: Identifying the components of Research Support facility (RSF) related to sustainable architecture

A1. Windows-East-facing: thermochromic windows on the east side of the building reduce the heat transfer in the winter.

A2. Windows-South-facing: Awnings shutters on the south front of windows divert direct sunlight to the roof meanwhile light shelves console below the window causes the reflection of light and shade on the window section without drawings.

A3. Windows-West-facing: Electrochromic windows get dark on the western front in the late afternoon to avoid the heat and unnecessary waste.

A4. Operable Window: Automatic and manual windows allow mutually ventilation.

B. Heating and Cooling: In the building of radiant heating and cooling was used to control the internal temperature. About 42 miles Radiant Piping in the building have been implemented.

C. Louvered Sunshade: Solar awnings shutters blocks radiation with high angle in the summer and instead of direct reflection of radiation, reflects it at an angle up to 30 degrees to the roof to.

Figure 6: Awnings shutters and their working mechanism

D. Roof-top PV: photovoltaic cells capable of producing 1.6 megawatts solar power have been installed on the roof and parking lot adjacent to the building to become a Net-Zero Energy Building.

E. Transpired Solar Collector: When the cold weather hits the collector, sunlight warms the black metal perforated panels and passively heat up the surrounding air space. Then the hot air is drawn into Labyrinth and circulates inside the building.

F1. Day lighting: Working rooms are located inside a large hall that none of the seperator walls are more than 54 inches in height to provide them optimal flow of air and daylight.

F2. Open-ceiling workstations: Working rooms have open ceilings to direct indirect light into the building's central core. None of them are no more than 30 feet from the nearest window.

G. Labyrinth: A labyrinth with massive concrete structure is located under the floor of the building in the form of channels that save thermal energy and creates additional capacity of passive heating energy to ventilze the system flowing beneath the floor.

H. Recycled Building Materials: the materials of the building features fast or renewable recycling. For example, the reprocessed gas steel pipes were used as the structural columns and recycled materials of the runway of Stapleton airport were used in foundation and ceilings.

I. Walls: Precast concrete insulating panels produces significant thermal mass and interior air temperature is adjusted with thermal inertia. Also, the paint of the interior walls with maximum reflection maximizes the daylight inside the building.

J. Flooring: the floor of the building was raised 12-inch to free the space below it for wiring electrical system. In addition, a dedicated ventilation system from the outside of the building provides fresh air when the windows are closed due to heat or cold air.

K. Landscape: the building site include Gabion walls, wire shelves filled with rocks and local plants irrigation systems and its controller. Also this center (RSF), was one of 150 projects from 34 states chosen as a pilot project to assess the level of ingenuity in the sites with sustainable architecture; A rating system was used for the first time at the national level to design green places and construction and maintain the facilities.

Conclusion

In this study, electrochromic smart glass as one of the types of smart glass and their characteristics as well as their practical application and advantages were investigated in two cases of study. Electrochromic smart glass provides architects and builders many opportunities and removes some of the former limits and opens new perspecives in design; such as much broader prospects and the possibility of controlling the amount of light and heat entering the inside and creates a more pleasant environment and the climatic than the past that provides the possibility to control and change and adapt more to the needs and wishes of its users and the optimal use of these facilities due to its complexity requires high level of knowledge and skill. By studying the two pilot cases in the world, Chabot College (CSSC) and Research Support Facilities (RSF) it was seen that glass and other smart materials in a unified and integrated unit the thinking of design based on the principles of sustainable architecture was used. And only the use of one or more smart materials, regardless of the above principle will not bring the expected performance. Combining old and acceptable elements and their use in traditional and ancient architecture such as atrium with new smart materials like what was done in Chabot College indicates the facts that the use of new achievements does not means rejecting acceptable and effective traditional and indigenous elements. It is important to remember that, unfortunately, in our country as an excuse to use modern technologies, past architectural tradition was forgotten and no attempts have been done to integrate and combine these two areas. Replacing new smart materials and sustainable design thinking with old materials and the design principles neglecting the issues of sustainability in building, lead to significant savings in energy consumption and consequently a significant reduction in environmental pollution. Therefore, it is necessary to pay more attention to the issue than ever before in our country. As the last word, each new smart materials have their limitations and special features that to use optimally, their nature shoul be first identified properly and away from fascination and rejection in order to be used in a proper place regarding the features they have.

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