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Review

Active dynamic windows for buildings: A review

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ABSTRACT

The objective of answering the growing demand of environmental comfort and the urgent need to improve energy efficiency of new and existing buildings, are determining an in-depth review of the features and requirements of the building transparent closures towards technological solutions that can guarantee along with a maximum thermal insulation, the possibility to regulate the incoming solar radiation or generate electrical energy.

Thanks to the huge progress in the field of materials science, a new class of highly innovative glazing systems is entering the market mostly by taking advantage of key enabling technologies such as nanomaterials or smart materials.

Among these new technologies, active dynamic glazing, by modulating the amount of entering near infrared radiation and visible light, allows significant energy savings, as well as ensuring greater thermal and visual comfort for occupants.

The article offers a thorough review of active dynamic glazing technologies on the market or in development, such as electrochromics, gasochromics, and further emerging technologies, including nanocrystal in-glass composites, electrokinetic pixels, elastomer-deformation tunable window, and liquid infill tunable window, comparing them in terms of operation, performances and building application potential, and providing relevant data to aid in understanding impacts on energy-efficiency and comfort.

Contents

1. Introduction

The building envelope plays a strategic role in the energy and environmental performance of buildings, significantly affecting the levels of indoor comfort. As it is known, it represents in fact an integrated system able not only to influence the flows of energy (heat and solar radiation) and matter (air and vapor), but also to convert solar, wind and mechanical energy into heat and electricity to meet the different demands of the building.

In this picture, the building envelope, and the transparent

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closures in particular, have become the main object of regulations and at the same time the main research, development and testing field for all agents involved in the building process, both in new constructions and existing buildings retrofit interventions [1–3].

The final objective is to obtain a new generation of advanced transparent closures, able to fully adapt to the environmental conditions in a dynamic way, ensuring, in full synergy with the systems and equipment, an efficient continuous and automatic management of all matter and energy flows in accordance to climate, user behavior, and market conditions of energy.

This means developing a new generation of glazing, not only capable of offering better performance compared to traditional solutions, but also to fulfil new functions such as power generation, self-cleaning, self-heating, and light and radiation control (see Table 1).

Thanks to the huge progress in the field of materials science, a new class of highly innovative glazing systems is entering the market, mostly by taking advantage of advanced key enabling technologies such as nanomaterials or smart materials [1–10].

The application of advanced coatings is in fact allowing to improve mechanical, physical and chemical performance of glazing by imparting it new properties, both fixed (low-emittance, anti reflection, scratch resistance, etc.) and dynamic (chromogenics, self cleaning, photovoltaics, luminescents, etc.) [6,11–14].

New dynamic glazing systems exploiting smart materials are also called smart windows, since they can autonomously and immediately adapt to the changed environmental conditions. A change in the values of the surrounding energy field, such as a variation in electrical, chemical, thermal or mechanical energy, determines in fact in these materials a spontaneous color change (chromogenics), chemical reaction (photocatalytics) or energy generation (luminescent and photovoltaics).

Among the possibilities offered by smart materials, selective and dynamic modulation of thermal energy and incident light, offered by chromogenic materials, represents a key element in the energy and environmental performance of the buildings [1]. With this aim, in the last decades innovative active dynamic glazing systems have been developed, able to control incoming solar radiation, in order to guarantee maximum visual comfort and to manage at best solar gain in hot and cold seasons [4,5,15].

Though thermal insulation of windows is in fact already well addressed even in products widely available on the market [4,5,12], the control of incident solar radiation, in order to optimize incoming thermal and lighting flows, is still particularly delicate and a key element for the achievement of indoor wellbeing and more generally of greater energy efficiency in buildings.

These innovative glazing systems could represent the best solution both for new constructions and existing buildings renovation

Table 1
Highly innovative glazing for the building envelope.

Glazing properties and technologies	
High fixed performance	**Anti reflectance.** Light transmittance maximization, daylighting improvement, photovoltaics yield increase. *Technology:* Polymer/oxides nanocoating • Ultra clear glazing **Low-e.** Thermal loss reduction. *Technology:* Metal oxides nanocoating • Advanced thermal insulation glazing **Anti scratch.** Durability increase. *Technology:* Silicon oxide nanoparticles • Scratch resistant glazing **Easy to clean.** Reduction of maintenance and detergents, daylighting improvement. *Technology:* Silicon oxide hydrophobic nanocoating • Easy to clean glazing
Smart performance	**Self cleaning.** Reduction of maintenance and detergents, daylighting improvement *Technology:* Photocatalytic titanium dioxide nanoparticles • Self cleaning glazing **Self heating.** Reduction of cold radiating surface, avoidance of condensation phenomena, interiors heating *Technology* a) Nanoplasmonic antennas • Passive self heating windows b) Metal coating with electrical current • Active self heating windows **Passive Dynamic control.** Solar radiation and glare adaptation, visual and thermal comfort *Technology* a) Thermochromic materials • Thermochromic glazing b) Photochromic materials • Photochromic glazing **Active Dynamic control.** Solar radiation and glare modulation, visual and thermal comfort, energy savings in HVAC and lighting systems. *Technology* a) Polarized particles • Suspended particles devices • Polymer dispersed liquid crystals • Electrokinetic pixels window b) Mechanochromic materials • Elastomer-deformation tunable window c) Electrochromic materials • Electrochromic devices (EC) • Nanocrystal in-glass composites window d) Chemochromic materials • Gasochromic window e) Mechanical actuation • Liquid infill tunable window **Energy generation.** Solar radiation shading, energy production. *Technology* a) Photoelectric materials • Crystalline and inorganic thin film glazing • Organic photovoltaic glazing • DSSC photovoltaic glazing b) Photoluminous materials • Transparent Luminous Solar Collectors c) Electroluminous materials • Transparent OLED glazing

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