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Energetic and visual comfort implications of using perovskite-based building-integrated photovoltaic glazings

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Abstract

Building integration of photovoltaics (BIPVs) has been recognized worldwide as a pivotal technology enabling the exploitation of innovative renewable energy sources in buildings, acting as electric power generators within the new framework of smart cities. Photovoltaic (PV) modules can be designed as relevant components of building envelopes, energy-producing units, fulfilling the multiple requirements of construction elements. Their integration in architectural glazings is still impeded by the inherent optical features of commercial solar cells, but also aesthetic, economic and social constraints, still acting as relevant barriers. In this roadmap, novel PV technologies could be effective drivers of a real change of paradigm. We have recently demonstrated that a coherent and exhaustive study of BIPV for semitransparent cells requires a "holistic approach", taking into account the complex fallouts of semitransparent modules on the energy balance, but also the full assessment of visual comfort benefits deriving from their integration in glazings. We have demonstrated that BIPV could offer manifold advantages: visual comfort effects comparable to commercially available solar control glasses and fair energy yield. Moreover, we found that in several cases the annual energy production overcomes the amount of electric energy used for artificial lighting.

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Keywords: Building-integrated photovoltaics; energy performance; energy simulation.

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1. Introduction

According to the agreement of COP21, global warming should be kept below 2 °C by means of a massive reduction of greenhouse gas (GHG) emissions. The building sector represents between 30% and 40% of the demand in final energy in developed countries, dramatically affecting GHG emissions and climate change. In order to mitigate this huge environmental impact, net zero energy buildings have been conceived, i.e. buildings showing annual zero energy balance. The Directive Energy Performance of Buildings, approved in 2002 and recast in 2012, requires that new buildings in the EU will have to produce the consumed energy to a very large extent employing renewable sources of energy [1]. At the same time, the traditional scheme of the electric grid, powering industrialized countries worldwide, based on its rigid basic components (generation, transmission and distribution of electric power), is a complex and fragile system, neither capable of storing electric energy nor of matching instantaneous changes of demand and offer. In such a framework, it is not possible to face the intrinsic intermittency and fluctuation of delocalized renewable sources. Re-engineered electric grids, named "smart-grids", and so on, can use digital information to cope with the deployment of stochastic renewable sources. In this roadmap, moving from a fossil fuel economy to an electricity economy, a strong effort to the effective exploitation of innovative renewable sources (e.g. photovoltaics (PV), wind energy, etc.) could bring manifold advantages: the attenuation of foreign dependence and a stimulus to a sustainable approach to development. Sunlight represents an abundant, inexhaustible and equally distributed renewable source of energy. 90 PW of radiant power is received continuously on the planet's surface: a far larger amount of energy respect to global rate of energy consumption: 17.2 TW in 2014. The amount of energy we can get from the average solar power striking the surface of Earth (170 Wm^{-2}) depends on the harvesting capacity of our technologies. In the same year, PV global capacity was almost 180 GW. With hydroelectric and wind renewable sources, they reached 20.6 % of world energy demand. [2]. Nowadays, PVs can be considered an established technology that can contribute significantly to lower GHG emissions and energy consumption in new buildings as well as in existing ones.

2. Open issues of BIPVs

Building Integration of Photovoltaics (BIPV) represents a relevant chance to improve building energy performance and to reduce their ecological footprint, especially in the future scenario of the smart-grid, promoting buildings to the role of small, delocalized power plants and simple energy consumers to the role of aware "prosumers". BIPV is a better alternative to Building Adopted PV (BAPV) systems, that are simply attached on exterior parts of architectures (on rooftops or facades). BIPV systems represent architecturally relevant components, capable of producing electric energy but also fulfilling complex requirements of building envelopes (aesthetic, economic, structural, acoustic, thermal, etc.) [3,4]. BIPV manufacturers have to face several barriers: the more convenient price of BAPV systems for roofings and opaque facades, the persistent lack of awareness of designers and consumers, the underestimation of the BIPV market in favour of "traditional" BAPVs. The convenience of BAPVs is also linked to the almost 7-fold drop of the PV module price in the last decade, mainly due to the 10-fold increase of the Chinese production. In 2014, [2]. According to IEA, only considering the leading industrial countries, BIPVs could even exceed an energy production of 1 TWhp. The complex design of these multifunctional architectural components requires both the consideration of regulation and technical constraints and a wide expertise on technical and aesthetic issues. Conversion efficiency and peak power production are relevant figures of merit but fail in envisaging the real energy production without taking into account, precisely, specific location, exposure and climate conditions, temperature coefficient or yearly degradation. For instance, shading due to chimneys or other obstructions could heavily affect energy production in some cases (c-Si solar cells) rather than in others, performing better even when partially shaded (a-Si solar cells). Expectedly, the BIPV market is dominated by BAPV systems for roofings and facades. The most difficult challenge is represented by the integration of PV systems in architectural glazings. Homogeneous, highly transparent and multifunctional PV technologies could act as relevant drivers towards the diffusion of BIPV for architectural glazings, overcoming the multiple barriers still impeding its widespread diffusion: several research groups have been attracted by this open issue. Some of the authors have proposed dynamic tintable glazings acting simultaneously as semitransparent PV systems and smart solar control devices [5,6]. The slow diffusion of BIPV is also a technological problem, especially with reference to semitransparent PV technologies, which require special considerations, pointed out hereafter. Zomer et al. [7] investigated the balance between aesthetics and performance in building integrated c-Si