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Comparing energy performance of different semi-transparent, building-integrated photovoltaic cells applied to "reference" buildings

Francesco Martellotta*, Alessandro Cannavale, Ubaldo Ayr

Dipartimento di Scienze dell'Ingegneria Civile e dell'Architettura – Politecnico di Bari, via Orabona 4, 70125 Bari (Italy)

Abstract

Semi-transparent, building-integrated photovoltaics (BIPVs) are receiving significant attention by several research groups, given their increasing efficiencies combined to improved visual performance (being cell transparency and color rendering index, two key features to ensure their widespread use). Several technologies have been developed in the last years, based on the use of amorphous silicon cells, Cu(In,Ga)Se2 (CIGS) cells, organic PV cells, photoelectrochemical (DSC) cells, and perovskite-based cells. Each technology has pros and cons, but among them the two most reliable and promising seem to be the first one (η_{STC}= 3-6% and T_{vis}= 7-40%) and the last one (η_{STC}= 6.6% and T_{vis}= 42.4%). The second, in particular, may be processed so to appear neutrally colored, resulting in a substantially gray glass, while the first one, absorbing nearly all the blue-green radiation, presents an orange-brown coloration. The paper investigates how the use of both technologies affects the energy balance of buildings. For this purpose the EnergyPlus platform was employed and two validated reference buildings were used for comparison (one residential and one office building). Energy yield due to BIPV technologies, variation in heating and cooling loads due to cell transparency, and implications on visual comfort and on artificial lighting usage are finally discussed

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

* Corresponding author. Tel.: +39-080-5963631
E-mail address: francesco.martellotta@poliba.it

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1. Introduction

Building integrated photovoltaics (BIPV) represent nowadays one of the most impressive opportunities in favour of a widespread use of energy producing devices. In fact, integration of PV elements in building components represents a major advantage compared to conventional building applied PV (BAPV) systems, where PV panels are simply attached on exterior parts of building envelopes (on rooftops or facades). Consequently, as BIPV systems represent architecturally relevant components, they require the complex fulfillment of multiple conditions (aesthetic, economic, structural, acoustic, thermal, etc.) [1]. Façade elements, and transparent components in particular, are among the most interesting parts of the building that can conveniently integrate PV technologies. They cover large unobstructed surfaces (particularly for high rise buildings), have several exposures (allowing to follow sun path), may easily integrate wiring and other systems. Thus, several researchers are now investigating the potential of this technology, with particular reference to semi-transparent devices. [2]

Amorphous silicon solar cells (a-Si) [3] have currently reached the best laboratory efficiency of 10.2% [4]. This technology takes advantage of a much lower consumption of silicon with respect to first generation PVs, a lighter substrate (glass), a consolidated industrial process, and, above all, its range of applications is widened by its semitransparency. Several low-cost, lightweight and flexible a-Si:H semitransparent solar cells have already been reported in the literature [5].

Among the other technologies, semitransparent PV glazing based on 1.2 μm thick CIGS solar cells were reported, with a conversion efficiency of 5.6%. [6], organic PVs, currently offering 11.5% efficiency, are investigated for use in semi-transparent devices although durability concerns are currently hampering its use [7]. Photoelectrochemical cells, also known as dye sensitized cells (DSCs) have been long considered as a promising technology for semitransparent PV devices. However, several concerns limit their reliability.

More recently, perovskite-based solar cells have been revolutionizing the field because they are easily-processable, offer high conversion efficiency (up to 22%). Several strategies have been proposed in order to realize highly transparent perovskite cells. Among the most successful, making thinner perovskite layers leads to obtain brownish cells [8,9], while controlling the perovskite morphology, as to fabricate discontinuous micro-islands by tuning the physical parameters of the perovskite deposition process [10] leads to neutral-tinted films, with minimal impacts on the spectral properties of light entering indoor.

When dealing with transparent components, energy saving concerns suggest limiting cooling loads in buildings by means of solar control glasses. On the other hand, visual comfort considerations suggest minimum acceptable values for glazing transmittance, to range between 25% and 38% [11]. Thus, integration of semi-transparent devices which simultaneously limit solar gains and produce electric energy may become an interesting opportunity.

More recently, Chae et al. [12] suggested a procedure to evaluate the energy performance of buildings incorporating BIPVs, considering not only the electrical characteristics of PV cells, but also thermal and optical behavior and the consequent implications on building energy performance. They found that the maximum electric energy generation using a-Si:H cells could range from 22 kWh/m^2 per year to 45 kWh/m^2 per year, depending on several parameters including the type of PV cell, the site location and the exposition. Oliver et al. [13] studied the influence of building integrated semitransparent solar cells on heating, cooling and lighting loads and electricity generation, considering parameters like window-to-wall-ratio (WWR) and cells average visible transmittance (T_{vis}). They found out a promising energy saving potential between 18% (WWR=33%) and 59% (WWR=88%), compared to regular glass.

Following similar researches [12,14], this study aims at comparing the energetic advantages resulting from use of more consolidated a-Si technologies with those resulting from perovskite-based cells. The a-Si cells are the only semi-transparent PV technology already available on market. Among the best performing cells, those used by Chae et al. (η_{STC}=5.30%, T_{vis}=0.41) [12] and by Lim et al. (η_{STC}=5.93%, T_{vis}=0.18) [15] are worth being mentioned. On the other side, the best perovskite based semi-transparent cells achieved an efficiency of 6.4% while keeping high visible transmittance (0.424) [16]. Results of the comparisons are shown below.