Energy & Buildings 166 (2018) 407–417

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

Optical, thermal, and energy performance of advanced polycarbonate systems with granular aerogel

Elisa Moretti[a,*], Michele Zinzi[b], Francesca Merli[c], Cinzia Buratti[a]

[a] Department of Engineering, University of Perugia, Via G. Duranti 93, Perugia 06125, Italy
[b] ENEA Casaccia Research Centre, Via Anguillarese 301, Rome 00123, Italy
[c] CIRIAF (Interuniversity Research Center on Pollution and Environment "Mauro Felli"), University of Perugia, Via G. Duranti 63, Perugia 06125, Italy

ARTICLE INFO

Article history:
Received 5 September 2017
Revised 17 January 2018
Accepted 31 January 2018
Available online 14 February 2018

Keywords:
Silica granular aerogel
Optical properties
Thermal properties
Advanced glazing systems
Polycarbonate panels
Building integration
Energy performance

ABSTRACT

Polycarbonate panels could be considered as a suitable and cheap solution for walls, roofs, and sheds in non-residential buildings and, at the same time, granular silica aerogel is one of the most promising nano-materials for energy saving in buildings. In the paper, three types of advanced multiwall PC panels (thickness 16, 25, and 40 mm) with translucent granular aerogel were investigated by experimental (thermal and optical) and numerical characterization. By comparing thermal performance of air and aerogel-filled PC systems, it can be noticed that the impact of the aerogel is remarkable: the reduction in U-value is 46%-68%, depending on the aerogel layer thickness. U-value is 1.4 W/m^{2}K for the 16 mm thickness sample and it is 0.6 W/m^{2}K when the thickness increases up to 40 mm. The systems keep their performance in horizontal position, when they are used as roofs. Light transmittance is 0.61 and 0.42 for 16 mm and 40 mm respectively and the reduction with respect to air-filled panels is acceptable (15%) for 16 mm and significant (40%) for 40 mm thickness. The aerogel has also a remarkable impact on the reflectance spectrum, especially between 400 and 1400 nm. The solar factor is 0.58 for 25 mm thickness, quite similar to the low-e glazing one. Finally, energy simulations for a case study showed that aerogel-filled PC systems outperform conventional double glazing systems both for heating and cooling energy demands. However, when compared to low-e glazings, the benefits of the translucent material (also considering the highest thickness) in the interspace are lower for heating and negligible for cooling energy demands. The aerogel-filled polycarbonate systems could be a valid solution for non-residential buildings, enhancing the thermal performance and the light control of the building envelope, especially when they are used as roofs.

1. Introduction

Transparent building envelopes play a significant role in energy performance, especially when considering highly glazed non-residential buildings. In order to reduce energy consumptions, a plethora of advanced materials for building envelopes have been investigating and they have been proposed in the market. Recently, a lot of attention has been devoted to nanomaterials, such silica aerogels [1–5].

Meanwhile, polycarbonate (PC) multiwall panels for building applications have been spreading in the market, because of the low weight, durability, fire, weather, and UV resistance. A lot of applications are allowed in fenestration systems, continuous windows, shed, roofs, and walls by employing products with different cell geometric characteristics, colors, and thicknesses. Moreover, PC panels are cheaper than conventional glazings and, once appropriately designed, they improve thermal performance reducing significantly energy costs, especially in commercial and industrial buildings.

In a previous study [6] multiwall air-filled polycarbonate panels were investigated as a solution for commercial and industrial buildings. The thermal and optical performance was assessed also considering the influence of male-female interlock junctions (which are used for in-situ installation) on their performance. The optical property measurements highlighted that a large integrating sphere is needed, due to the geometry and structural complexities, as well as for scattering phenomena in non-regular materials [7]. Moreover, the geometry of the samples showed that the PC panels optical properties have an angular dependence, much more than in conventional glass units [6]. Furthermore, the panel joints can influence thermal and optical performance: the variation could be positive or negative, depending on the number of layers and on the sample characteristics. All the polycarbonate multi-sheets panels showed good thermal performance: the U-values are com-

* Corresponding author.
E-mail address: elisa.moretti@unipg.it (E. Moretti).

https://doi.org/10.1016/j.enbuild.2018.01.057

prised in the 1.2−1.9 W/m^{2}K range, depending on the sample features, quite similar to the values of double glazing units. At the same time, the complexity of the geometry allowed a reduction in light transmittance (about - 30% with respect to a conventional DGU (DGU = Double glass unit)) and an increasing in solar transmittance. However, these systems are light diffusing, preventing from glare problems and improving visual comfort [6].

When higher thermal insulation levels are required, granular silica aerogels can be used in order to fill the air gaps in the panels. Aerogels are nanostructured solid materials with high porosity (> 90%) and low density (80–200 kg/m^3), which can be defined as superinsulation materials, due to their low thermal conductivity, comprised in the 0.012–0.023 W/mK range, depending also on the granule size [8,9]. Due to these interesting properties, the granules have been successfully incorporated in different innovative aerogel-based solutions for energy saving in buildings, both opaque, such as concrete, plasters [10], flexible blankets [11], and translucent, such as highly energy-efficient windows [12–15]. Granular aerogel in glazing systems does not allow the view through it: a completely diffuse light transmittance could be achieved, also contributing to reduce glare problems. Thermal, optical, and acoustic performance of glazing systems with silica aerogels is widely discussed in the literature [16–23], whereas detailed studies on advanced aerogel-filled PC systems are lacking.

Buratti et al. [23] recently investigated thermal and optical properties of a double glazing (4 mm float clear glasses) with only 15 mm of silica granular aerogel in the interspace. The experimental results highlighted the aerogel impact on heat transfer in the glazing: the thermal transmittance was 1.0–1.1 W/(m^{2}K), allowing a 63% reduction when compared to conventional DGU with air, together with a good optical behavior: the light transmittance is 0.57, corresponding to a 30% reduction with respect to air-filled DGU. However, when the aerogel thickness increases up to 60 mm, a U-value of 0.3 W/(m^{2}K) could be achieved [20,23]. The light transmittance of granular aerogels is about 80% considering 10 mm thickness and it decreases by 20% each 10 mm thickness increasing [13]. However, optical and thermal performance is significantly affected by the particle size of the aerogel granules [8,11,18].

Huang and Niu [24] studied the energy performance of aerogel glazing systems in humid subtropical cooling-dominant climates: in a commercial building in Hong Kong, aerogel glazing systems can reduce the total annual space cooling load by about 4% with respect to conventional windows, while the annual cooling load reduction is comparable to the one achieved by application of a shading-type low-e glazing. The results highlighted that glazing systems with granular aerogel in interspace could be a suitable solution for energy saving in buildings, also considering cooling-dominated climates. These findings were confirmed by Ihara et al. [22], who investigated the energy performance of granular aerogel glazings used as spandrels. The results showed that the considered systems allowed a lower energy demand than a double glazing facade in cooling dominated climates, namely Tokyo and Singapore. In heating dominated climates (Oslo), the aerogel granulate glazing facade does not achieve the same performance of triple glazings. However, a combination of aerogel and triple glazing systems could be a suitable solution for cold climates. Buratti et al. [25] studied the energy performance of glazing systems filled with granular and monolithic silica aerogel as a solution for the refurbishment of an Evolutive House built in Perugia (Italy) in 1978. The results showed that an important energy saving was obtained for all the proposed glazing solutions (about 60–70%).

An experimental investigation on two prototypes of polycarbonate panels filled with granular aerogel (6 mm and 10 mm aerogel thickness) was carried out by Dowson et al. [26]. Considering the retrofit of an office building in London (UK), the prototypes were installed on an existing single glass window, with a 15 mm air gap between the PC panels and the glazing. In-situ measurements highlighted excellent performance of the proposed solutions: the heat flux reduction was about 73% for 6 mm aerogel PC panel and it increased up to 80% considering 10 mm of aerogel; at the same time, the light transmission decrease in was acceptable: light transmission values through the 6-mm aerogel PC panel, 10 mm aerogel PC panel, and the control single glass were 58%, 51% and 73% respectively.

Starting from the previous findings, in the present paper, advanced polycarbonate panels with aerogel are studied in terms of thermal, optical, and energy performance. An extended experimental campaign starting from the preliminary results obtained in [27] is presented for three types of aerogel-filled polycarbonate panels, considering different thicknesses and geometry (total thickness of 16, 25, and 40 mm).

A large sphere apparatus [28] was used to accurately investigate optical properties of these complex transparent systems, characterized by a scattering nature [6,7]. The equipment available in ENEA (Rome, Italy) allowed a careful optical characterization of the panels, due to also depending on the light incidence angle (0°; 30°; 45°; 60°). The broad band properties (Light transmittance τ_v, Solar transmittance τ_e, and Light ρ_v and Solar reflectance ρ_e) were then calculated in compliance with EN 410 [29], by using the spectral transmittance and reflectance data.

Thermal performance was investigated by means of the guarded hot plate apparatus and the U-value was calculated [30]. The proposed solutions are often used roof solutions in buildings, due to their lightness: in the experimental campaign the U-value was measured also considering the sample in horizontal position.

In order to evaluate the impact of aerogel on optical and thermal performance, the measurements were performed also considering the empty panels, without aerogel in interspace.

The solar factor was estimated following the procedure suggested by the EN 410 and ISO 9050 standards [29,31], considering the PC panels as multiple glazing systems: the calculation of the properties of the assembled product was carried out [31] starting from single PC layer data measured using a conventional spectrophotometer, available at the University of Perugia Labs.

As final output of the study, the accurate experimental analysis and the estimation of the solar factor provided reliable data which were used as inputs for building energy simulations in a case study in different climate conditions (hot, moderate, and cold) and their energy performance was finally compared to the one of conventional double glass units.

2. Materials and methods

2.1. Samples

Advanced aerogel-filled polycarbonate panels were introduced in the market quite recently and they have been widely used in the USA and Northern Europe as skylights, roofs and walls in non-residential buildings (Fig. 1).

In the paper, three aerogel-filled multiwall polycarbonate panels were investigated. Each sample is formed by three walls, two external (with a thickness of 1 mm) and an internal one (0.4 mm thickness), and the granules of aerogel are sandwiched in between (Fig. 2a). They differ in geometry (the orthogonal layers have a different distance) and thickness (Table 1 and Fig. 2b): PC 16-AER (16 mm total thickness), PC 25-AER (25 mm total thickness), and PC 40-AER (40 mm total thickness). Granular aerogel are characterized by diameter of the particles in the 0.7–4.0 mm range [32]. The maximum size of polycarbonate panels is 2100 mm (width) × 7000 mm (length) and they are installed by means of male-female joints.