Energy and Buildings 109 (2015) 35–46

Contents lists available at ScienceDirect

Energy and Buildings

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

Thermal-physical behavior and energy performance of air-supported membranes for sports halls: A comparison among traditional and advanced building envelopes

Hua Suo[a], Adriana Angelotti[b,*], Alessandra Zanelli[a]

[a] Architecture, Built Environment and Construction Engineering Department, Politecnico di Milano, Milano, Italy
[b] Energy Department, Politecnico di Milano, Milano, Italy

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form
25 September 2015
Accepted 1 October 2015
Available online 9 October 2015

Keywords:
Textile architecture
Fabric
Membrane
Air-supported structure
Pneumatic envelope
Cushion
Dynamic simulation
AFN
Energy performance
Comfort

ABSTRACT

In the last decade textile architecture has become increasingly popular: fabrics and foils are more and more used as skins for permanent and enclosed buildings. The thermal-physical behavior of air-supported membrane structures, characterized by low thermal inertia and poor insulation, is definitely different from the traditional architectures, although required comfort levels are often similar. While the thermal behavior of the wider spread ETFE foil cushion system is still investigated, a quantitative assessment of the double-layered fabric skin energy performance is still lacking. This paper studies the latter membrane system, focusing on the evolution of air-supported envelopes for sports halls, from single layer to double layer membranes, either based on pneumatic cushions or on continuous air gaps. By performing measurements on running sports halls and dynamic simulations, the winter energy performance, the comfort conditions and the internal surfaces condensation risk of a typical sport hall in Northern Italy are evaluated. An insight is given into the envelopes dynamic behavior and energy balance. Double layers envelopes allow saving from 11% to 18% of the heating energy compared to single layer. Moreover, further energy saving strategies are proposed and quantified, considering low-emissivity coatings, reduction of the cracks areas, modifying indoor air set points.

1. Introduction

Pressostatic envelope systems are tensile membrane structures supported by air, where the fabric layer is stabilized by a positive differential pressure between the inner and outer sides, in order to maintain their form under external loads. This building technology has been developed since the end of the 1950s, while recently it has been updated more and more through a wide variety of durable and translucent technical textiles (i.e. PVC coated polyester) and self-cleaning, transparent films (i.e. fluoro-polymeric foils of ETFE) [1].

Traditionally pressostatic envelopes provide the location for temporary events, although in the last decade the range of uses has been extended to a wider variety of typologies [2]. Permanent, seasonal or ephemeral buildings can be mainly distinguished, where a pneumatic or inflatable skin is able to protect courtyards in educative and residential buildings, to cover sports halls during the winter season, or even to perform a temporary pavilion for shorter service life [3]. Especially in permanent or semi-permanent applications HVAC systems are often required to maintain hygro-thermal comfort conditions. In this regard the air inflation system can also serve as the heating/cooling system.

Following this emerging trend, more and more attention should be paid to the membrane envelope thermal-physical properties in order to improve indoor comfort conditions and to reduce climatization energy consumption. Thus envelopes made up of double or multiple layers pneumatic cushions are increasingly used instead of single layer envelopes. Although translucent double skins made of technical textiles are quite common as a permanent building (e.g. the Serpentine Sackler Gallery by Zaha Hadid in Fig. 1), the transparent skins performed by ETFE foil cushions (e.g. the Khan Shatyr Entertainment Centre by Foster and Partners, Fig. 2) are mainly investigated [4–7]. For the pneumatic cushions a center-of-the-cushion thermal transmittance can be identified. As it happens in glazing systems, the thermal transmittance or U-value is dominated by surface thermal resistances in the single layer case, and by air gaps resistances in the multiple layers situations. By passing from single to double layers cushions the U-value

* Corresponding author.
E-mail address: adriana.angelotti@polimi.it (A. Angelotti).

http://dx.doi.org/10.1016/j.enbuild.2015.10.011
0378-7788/

Fig. 1. Zaha Hadid Studio, Serpentine Sackler Gallery, London. Permanent building with double textile membranes roofing system integrated with glazing eyes on the top. (Copyright reproduced courtesy of Architen Landrell Associates.)

roughly halves, passing from about 6 to 3 W/(m^2 K). Knippers et al. [1] conclude that the choice of the *U*-value calculation method is not critical, but rather the horizontal/vertical installation of the cushion, determining the direction of the heat flow and thus the natural convection effectiveness. Thermal bridges at the cushion edges, due to the clamping or to the welding, usually increase the heat transfer across the cushion. In order to avoid thermal bridges effect a new generation of pressostatic double layers envelopes has recently been proposed. In this case a gap is created between the two envelopes and an air flow rate is continuously injected into the gap in order to keep the two membranes separated.

Although the structural behavior of fabric envelopes is well established, a few studies [8–10] focused on their overall thermal-physical behavior. According to [8], membranes enclosures are highly sensitive to changes in outdoor environment due to their low thermal inertia. Moreover they may be affected by indoor air thermal stratification, caused by the large air volumes and by the internal surface temperature difference between the membrane and the more massive components such as the floor.

Summer behavior of a test membrane open to the environment was analyzed both experimentally and numerically by He and Hoyano [9]. They show that solar transmission is one of the key factors affecting the thermal environment of the space under the membrane structure and that simulation tools can be used to quantitatively predict the impact of materials properties on it. As a further step, He and Hoiano [10] propose to couple the thermal simulation with computational fluid dynamics (CFD) in order to evaluate the effects of a passive cooling strategy based on an evaporative cooling pavement.

Fig. 2. Foster & Partners, Khan Shatyr Entertainment Center in Astana, Kazakstan, 2012. An elliptical tent with a 200 m base and 150 m height, with a structure made of steel cables and an envelope of ETFE transparent pneumatic cushions, screen-printed with aluminum powder. (Copyright reproduced courtesy of Vector Foiltec.)

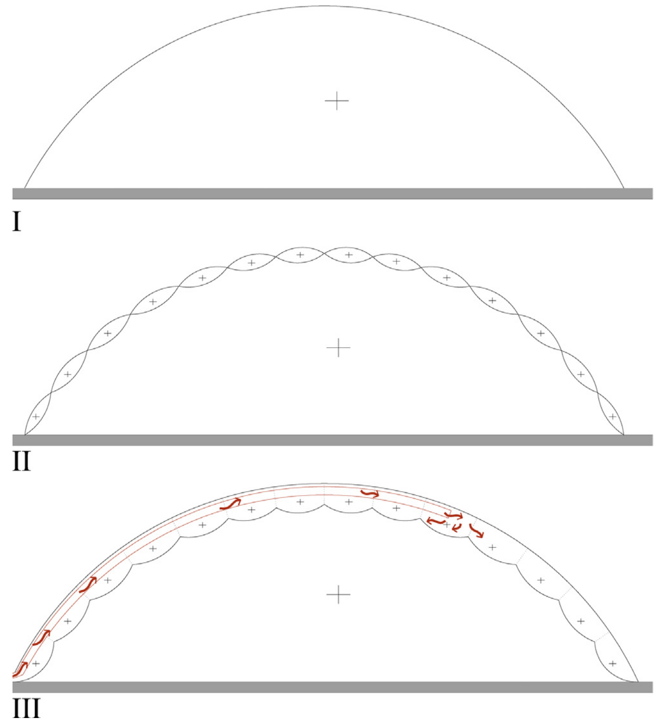

Fig. 3. Schematic section of 1st, 2nd and 3rd generation.

However to the best of the authors' knowledge no comparative assessment of the energy performance of the different kinds of membrane envelopes, namely single layer (referred in this paper as 1st generation), double layer made up of cushions (in this paper referred as 2nd generation) and double layer based on a continuous air gap (3rd generation), has ever been carried out. Therefore the present study aims at investigating the thermal-physical behavior of those three main kinds of envelopes (see Fig. 3), assessing the thermal comfort conditions and the condensation risk and finally quantifying the energy saving achievable passing from single to double layers constructions. Moreover, further energy saving strategies are proposed and analyzed. The case study consists of a sport hall adopting an air-supported fabric envelope for winter operation in Milano, Northern Italy.

The methodology adopted consists of:

- site surveys on running sports hall adopting the analyzed envelopes, in order to measure some relevant parameters and to verify some simplifying hypotheses on the thermal-physical behavior;
- set up of simulation models for the three envelope generations and dynamic simulations performed with ESP-r tool [11].

2. Case study

The dimensions of the analyzed sport hall are 36 m×36 m with a maximum height of 10 m at the center. The total indoor volume and plan surface are 8940 m^3 and 1888 m^2, respectively. The hall is provided with an air heating system mixing fresh air from outside