Applied Energy 159 (2015) 490–501

Contents lists available at ScienceDirect

Applied Energy

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

Building envelope with a new aerogel-based insulating rendering: Experimental and numerical study, cost analysis, and thickness optimization

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HIGHLIGHTS

- We present a recently developed silica aerogel insulating rendering.
- Its thermal performance is tested on a full scale house for the first time.
- A numerical model is developed using EnergyPlus.
- The rendering's thickness is optimized for different climates based on cost analysis.
- Sensitivity analysis is done to determine the thickness dependency on some variables.

ARTICLE INFO

Article history:
Received 2 September 2014
Received in revised form 15 July 2015
Accepted 19 August 2015

Keywords:
Aerogel based rendering
Optimum insulation thickness
Building rehabilitation
Experimental house
Dynamic thermal simulation
Payback period

ABSTRACT

In France, renovation of existing buildings has a high priority. The thickness of insulation layers becomes a major issue of concern especially in cities. In this study, we present a recently developed insulating rendering based on silica aerogels that can be applied to new buildings and to retrofit existing ones. A full scale experimental house is built near Chambery in France, with the rendering applied on its external facades. The results of a numerical model developed in EnergyPlus are compared to the on-site measurements. After validating the numerical model, the thickness of the rendering is optimized based on a cost analysis for different climates for the case of retrofitting an old building. Then, a sensitivity analysis is carried out to determine the thickness dependency on annual heating load, present worth factor, rendering's cost, and heating set-point. Results show that the optimum rendering thickness is in the range of 1.7–4.4 cm and the payback period in the range of 1.4–2.7 years depending on the climate. The optimum thickness increases with the increasing heating set-point and increasing present worth factor; however, it decreases with the increasing rendering cost.

1. Introduction

In France, buildings account for about 43% of the total energy consumption [1]. This energy consumption contributes to producing around 25% of CO_2 emissions. France has already adopted the objective of reducing its energy consumption and greenhouse gas emissions by a factor of four to five by the year 2050 as a part of its national strategy for sustainable development introduced in June 2003, and it's Climate Plan introduced in July 2004. The new thermal regulations (French RT 2012) limit the annual primary energy consumption for new buildings to 50 kW h/m^2 of floor area. The building sector offers significant potential for improved energy efficiency through the use of high-performance insulation and energy-efficient systems.

For existing buildings, renovation has a high priority in many countries, including France, because these buildings represent a high proportion of energy consumption and they will be present for decades to come. Until the year 2009, the residential building sector in France counted around 32.2 million housing units with an annual energy consumption of about 494 TW h [2]. Several studies [3–5] showed that the most efficient way to curb the energy consumption in the building sector (new and existing) remains the reduction of the heat losses by improving the

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http://dx.doi.org/10.1016/j.apenergy.2015.08.090
0306-2619/

insulation of the building envelope. A step beyond the current thermal performance of building envelope is essential to realize the intended energy reduction in buildings. For retrofitting and even for new buildings in cities, the thickness of internal or external insulation layers becomes a major issue of concern. Therefore, there is a growing interest in the so-called super-insulating materials, such as Aerogels.

Silica aerogels are silica-based dried gels having very low weight and excellent thermal insulation performance. Specifically, they have high porosity (80–99.8%), low density, and low thermal conductivity (0.014 W/(m K)) [6]. Silica Aerogels are an innovative alternative to traditional insulation due to their high thermal performance, although the cost of the material remains high for cost-sensitive industries such as the building industry. Research is continuing to improve the insulation performance and to decrease the production costs of aerogels. Two different types of silica aerogel-based insulating materials are being used in the building sector. The first is the opaque silica aerogels-based materials and the second is the translucent insulation materials.

Aerogel blankets/panels have started to be used to insulate building walls, grounds, attics, etc. Aspen Aerogels Inc. developed an insulation blanket based on silica aerogels, Spaceloft® [7]. A case study was done in the United Kingdom where a number of governmental housing units were retrofitted by adding Spaceloft® insulation layer at the interior wall surfaces. A 44% reduction in the *U*-value, a 900 kWh/year energy reduction, and a 400 kg/year carbon emissions reduction were obtained. In another study, thermal performances and experimental tests were performed on walls and roofs using aerogel insulation [8]. Hot box measurements on wall assemblies containing aerogels showed that the *R*-value of wood framed walls is improved by 9% and that of a steel framed wall by 29%. Chen et al. [9] reported on the development of a truss-core sandwich panel filled with compacted aerogel granules, designed to provide both mechanical support and thermal insulation.

Another type of silica aerogel-based materials used in buildings is the translucent insulation materials type. These materials have the advantage to combine a low thermal conductivity along with high transmittance of solar energy and daylighting. Research has been conducted in the last decade on the development of highly insulating windows based on granular aerogel and monolithic aerogel [10–16].

Baetens et al. [17], Cuce et al. [18], and Koebel et al. [19] conducted a review on the knowledge of aerogel insulation in general and for building applications in particular. All these presented a review of aerogel-based panels, blankets, and glazing systems. However, a very limited number of studies exist on aerogel-based thermal insulating plasters. Barbero et al. [20] provided an overall analysis of thermal insulating plasters in the European market. They concluded that innovative solutions for thermal insulating plasters based on materials with pore size in nanometer range, such as aerogel, could make a significant contribution to this field, reaching higher level of thermal performance and reducing the needed thickness. Additionally, successful approaches will have the ability to be used on both new and existing buildings, using techniques that are familiar to today's construction industry. According to the authors, thermal insulating plasters have the advantage of being applied on non-aligned, out of square, or, even, curved areas. They are flexible and can be suitable for any architectural and design solutions. Their easy application on the facades facilitates the rehabilitation of existing buildings.

In this study, we present a recently developed thermal insulating rendering based on silica aerogels that can be applied to new buildings and to retrofit existing ones. The objectives are to examine its performance on a full-scale house and to optimize its thickness for different climates. First, a full-scale experimental house was built where this rendering was applied on the external surfaces of its facades. Second, a numerical model was developed using the whole building energy simulation program EnergyPlus. The simulation results of the latter were compared to the on-site measurements. Third, the thickness of the rendering was optimized for different climates based on cost analysis over the life time of the building. Finally, a sensitivity analysis has been carried out to determine the variation of the optimum thickness with respect to several parameters.

2. The new aerogel-based rendering

An insulating rendering based on the (super)-insulating materials silica aerogels has been developed (Fig. 1) [21–25]. The invention is a light mortar that can be applied to the external surface of a building to produce a thermally insulating rendering. It consists of a mineral and/or organic hydraulic binder, an insulating filler comprising granules of hydrophobic silica aerogel (or a powder of this material), a structuralizing filler (option), and additives (option).

The aerogel granules are an industrial product manufactured separately in a specialized plant which are obtained by treating a hydrophobic silica organogel with a hydrophobizing agent in the presence of acid and in a solvent, separating the obtained hydrophobic organogel and removing the solvent by evaporation of the organogel [26]. The starting materials, namely silica organogels are produced by controlled hydrolysis of organosilicon compounds in organic solvents.

Thus, the mortar is made from these aerogel grains that somehow replace the sand used in conventional mortar.

The inorganic hydraulic binder is selected from the group comprising: alumina cements (preferably sulfo-aluminous cements and cements calcium aluminate base), Portland cements, lime, and calcium sulfates.

The organic binder is selected from acrylic and vinyl resins, preferably styrene-acrylic resins, acrylic, ethylene vinyl acetate, vinyl acetate/versatate/ethylene.

The structuring filler is selected from mineral fillers, preferably from sands.

The additives include a thickener (selected from modified polysaccharides), water retention (selected from cellulose ethers), and air-entraining (selected from surfactants).

Fig. 1. The new aerogel-based rendering.