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The thermophysical behaviour of cork supports doped with an innovative thermal insulation and protective coating: A numerical analysis based on in situ experimental data

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ABSTRACT

In this work, the thermal potentialities of insulation panels made of cork have been explored by means of a numerical approach based on experimental data. A comparative analysis between the panel in unaltered state, and then covered with an innovative shield coating (COIB 250®) was carried out. In addition, a defect simulating an inner detachment of the panel was fabricated to understand its behaviour during a daily solar thermal load. The site was selected *ad hoc* to avoid any shadow cast effect on the panel itself and any conduction phenomenon from the surrounding area. The external floor on which the panel was mounted was completely isolated from the soil. Two similar days with clear sky conditions were selected, real meteorological data recorded by a weather station installed near the inspected site and data deriving from a NASA software were used respectively for the ambient temperature and for the solar radiation, in order to provide a solid discussion of the findings. Results show how a cork panel, usually employed in civil engineering as an insulation system, may benefit a lot of a shield coating. The latter product tends also to minimize the impact of a subsurface detachment during the thermal conduction via heat transfer; this behaviour will be in-depth clarified in this work.

1. Introduction

The principles and concept of sustainable development can be dated back to early 1970s [1]. And from then on, awareness of the need for energy policies on one side, and energy consumption on the other, are growing constantly with time, in the last years this is still more evident, due to the population growth, generally associated with demand for buildings, services and comfort, that can be easily translated in increasing energy demand. By the way, it is common knowledge that in developed countries the building sector (buildings and related services) is responsible for about the 40% of the total energy use [2,3]. As a natural consequence, increasing energy efficiency especially in the building sector following all the possible directions becomes a basic need.

At an International as well as at EU level, the reduction of energy consumption is one of the most effective strategies considered. This is achieved improving existing buildings by means of green or energy efficient retrofits, and designing buildings with high energy performances. In Europe, and consequently in Italy, reaching a Near-Zero Energy Building (NZEB) has been set as a goal for the public sector starting from 2018, and for new buildings starting from 2020 [4]. To reach this goal, several strategies have been studied and experimented, at an urban scale level [5–7] as well as single-building scale level [8–11].

Thermal insulation materials play an important role in this challenge because of their influence on the energy required to maintain desired interior temperatures and on the environmental impact and embodied energy of the building. In particular, the ongoing development of novel and innovative construction materials raises questions about their ability to improve the energy performance of buildings, especially in real applications. Part of the European market for insulation materials is based on alternative and renewable materials, whose importance is increasing due to the minimization of the use of non-renewable materials to reduce

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the environmental impact of buildings, although they are still in a research and application phase and consequently not implemented in the building sector [12]. Among the others, cork is one of the most widespread natural and renewable materials used as thermal insulation, thanks to the elasticity of its constituent cells and to the air entrapped within, representing a large part of its apparent volume. Cork thermal insulation is primarily made from the cork oak, and can be produced as both a filler material or as boards. Typical thermal conductivity values for cork are between 40 and 50 mW/(mK) [13,14]. Its low thermal conductivity, together with a good compressive strength, make it an excellent material for thermal insulation where compressive loads are present. Among other applications, cork may be assembled in corkboards. An important advantage of corkboard is its resistance to chemical and biological agents [15]. Insulation corkboard agglomerates have three principal applications: thermal insulation, acoustical absorption and vibration damping. Corkboards maintain their physical properties to lower temperatures than other insulation materials (working temperature range − 180–110 °C) and under fire conditions do not release toxic substances as may occur with alternative materials such as polyurethane foams, or extruded polystyrene. Thanks to these features, cork agglomerates are suitable for diverse construction applications, interior or exterior walls, buildings and ceilings, to provide thermal (as well as acoustic) insulation [16].

Many studies have been developed considering cork as insulation material for construction applications. González et al. [17] determined the physical and mechanical properties of laboratory concrete made with different proportions of cork powder. Hernández-Olivares et al. presented an experimental analysis on a new material made up of cork-gypsum composite [18]. The authors discovered that its thermal insulation properties are quite good as a result of the thermal conductivity tests. In 2012, a research based on oak wood cork was experimentally realized by correlating dimensional stability, air humidity and the content of liquid water during an external load in service applied in Ref. [19]. Cork was also used in asphalt mixtures along with rubber granulates as partial aggregate substitutes [20]. El Bakkouri et al. presented in 2000 a general method for the simultaneous identification of the thermal diffusivity and of the surface transfer coefficients of a single-layer or multi-layer building surface [21]. Cork was one of the three materials analysed in the study. In 2005, Merino et al. presented several types of prefabricated elements, manufactured with cork and lightened plaster, which improve the similar systems on the market [22]. In Ref. [23] ANSYS® was used to analyse the mechanical behaviour of constructive elements made of plaster lightened with cork in the design phase, prior to the laboratory tests stage. The thermal behaviour of a type of granular cork bound with two different binders (*i.e.*, cement mortar and plaster) was studied in Ref. [24] without using the finite element method (FEM). The thermal behaviour of this material was also discussed in Ref. [25], in which granular cork was embedded in plaster obtaining a composite: the preliminary findings indicated that the composite is better than plaster in terms of thermal insulation, energy storage capacity and lightness. Cherki et al. [26] also studied the thermal properties of gypsum based composite material with embedded granular cork by varying the granular cork size and using the asymmetrical transient Hot Plate method. A cost evaluation of cork-based mortar for thermal bridges correction in a dwelling was performed in Ref. [27]. The results showed that the use of CH70 mortar for thermal bridge correction has a payback of 3 years when compared to the simple repair of the original external plaster. Mounir et al. studied the thermal inertia and thermal properties for walls coated by the sealants, *i.e.*, white cement-cork, cement mortar-cork and plaster-cork. An analysis of thermal conductivities, thermal effusivities and thermal diffusivities on the same type of materials was performed [28]. Instead, the in situ thermal performance of seven internal insulation options, on a historical brick wall, using heat flux sensors (*U*-value measurement), thermal imaging survey, and internal wall temperature was investigated in Ref. [29]. Cork lime was applied as insulation among many other products. Their performance was compared to a traditional lime plaster finish.

In this paper, the authors present the experimental and numerical analyses conducted via thermographic method and simulations on an insulating panel made of cork with the aim of understanding the thermal insulation effect and the lag effect of this kind of material in a real context. Firstly, a single cork layer has been analysed under solar loading conditions [30]. Then, a further analysis has been carried out coating with a thermo-shield top coat layer (COIB250®) on the radiated surface (named as front side). In addition, a defect was created on the rear side of the panel by using a sponge insertion confined inside the cork material. Provided the importance given, over the last few decades, to designing and implementing building envelopes for optimal energy performance, it is currently possible to predict the behaviour of new materials via *in situ* measurements. Consequently, an inspection done with a thermal camera operating into the long-wave infrared spectrum (7.5–13 μm) was useful to retrieve/confirm the emissivity values both of cork and COIB250® (*i.e.*, the thermo-shield top coat). These values were used within the Comsol Multiphysics® computer tool to work with real environmental recorded data. The same test area (*i.e.*, the region of interest – ROI) was selected. Results obtained are of interest in real life conditions, *e.g.*, when the panels are installed at the corner of a façade. Basing in fact on the 24 h numerical simulation results, the insulating behaviour of a thinner layer of shield coat superimposed to the cork panel was checked and compared to the performance of the simple cork layer. Thanks to the analysis of the temperature field via virtual probes positioned on the ROI, an improvement of the insulating properties of the multi-layer was observed. The use of such probes emphasizes how the numerical approach is useful to direct the selection of the experimental tests only towards powerful scenarios.

In the following, after a presentation of materials and site of application (§2), a description of the numerical approach is presented with special care to the definition of the mesh (§3) for the three cases of simple cork panel, cork with coating and cork, coating and sponge insertion simulating a detachment. In §4 results and discussion show the data obtained from the experimental/numerical analysis, leading to conclusions and future perspectives (§5).

2. The panel and the site

The panel was the CORKPANEL® by Tecnosugheri, with sizes 1000 [mm] long, 500 [mm] wide and 30 [mm] thick. The granulometry of the panel appears coarse (Fig. 1a), which is typical of toasted cork for insulating applications. It is very compact and structurally rigid to the out-of-plane bending. The latter property provides the ability to stay upright without support. For the test, a position that ensured the maximum sunshine throughout the day was selected, e.g. avoiding shadowing by buildings and trees.

Subsequently, a layer of COIB250® was applied on the front side of the panel. This insulating material has a thickness of 3 [mm], and visually it is similar to a plaster (Fig. 1b). It was applied following a homogeneous distribution both in plane and out-of-plane. In addition, this layer is connected to the base of the panel, forming a single piece with the cork. On the rear side of the panel, a typical bonding defect was fabricated to simulate a frequent defect in building insulations (Fig. 1c). In fact, during the installation of insulating panels, a lack of continuity (*i.e.*, an inclusion of air) between them and/or with the wall of the building is often present. Using a special tool, a parallelepiped 0.05 [m] long, 0.05 [m] wide and 0.02 [m] thick was initially removed. Then, a piece of sponge with a known porosity