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A composite cool colored tile for sloped roofs with high 'equivalent' solar reflectance

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ABSTRACT

Mediterranean cities are characterized by sloped roofs with ceramic tiles of traditional colors such as brick red in different tones. Their solar reflectance is generally low and can cause overheating of the building due to solar gains during the hot season.

In this work, an innovative approach is tested to achieve roof tiles with high capacity of rejecting solar radiation. It consists of using a cool-colored tile with relatively high solar reflectance, combined with a thin insulating layer attached below the tile and made of a silica-gel super-insulating material. An aluminum foil with very low thermal emittance is also applied below the insulating layer. Along the perimeter of each tile, line brushes are attached in order to enclose an almost sealed air space between the aluminum foil and the roof slab below when the tiles are supported on wooden battens.

Composite tiles like that outlined here can provide a strong increase of roof thermal resistance, helpful to control either heat loss in winter, or building overheating in summer. They can be installed onto an existing roof, for instance the sloped tile roof of a historical or traditional building, with no need to modify the roof height and structure.

1. Introduction

In the last decades the urban heat island (UHI) phenomenon more and more affected the temperature of urban areas, with a sensible increase of air temperature in comparison with the surrounding rural areas. Both controllable and uncontrollable causes may origin UHI; among the latter ones anticyclone conditions, extremely hot seasons, sun intensity, wind speed and cloud cover can be found. Urban design and structure related variables (sky view factor, green areas, building materials), or population related variables (anthropogenic heat and air pollutants), are among controllable variables as reported by [1]. Several consequences are originated by the UHI, the most important ones being the significant change of climate, the increase of greenhouse gases and CO_2 emissions, and the increase of energy consumption of buildings due to the larger use of electricity for air conditioning.

In the last decades the attempt to reduce UHI stimulated the research of several solutions such as solar reflective surfaces [1]. The first studies were carried out since the late 1990s when LBNL scientists started to analyze how high albedo materials can either mitigate UHI [2] or reduce energy use [3,4], as well as improve air quality [5]. Studies started in southern U.S., but they were then widened to consider different areas and climates [6]. More recently, in 2012, further analyses on the benefits related to reflective roofs and pavements use were made both in the U.S. [7] and in Europe [8]. Along the years, several generations of cool roofing materials were implemented, as reported in Santamouris [9].

Not only the increase of solar reflective areas but also green surfaces such as green roofs were widely analyzed. Studies on the energy and environmental performance [10] and the surface heat budget [11] of green roofs were carried out more than a decade ago, also trying to establish models for building energy simulation programs [12]. More recently, investigations were made on building energy savings [13], pollution abatement [14] and mitigation potential related to green roof in specific areas such as Chicago [15], tropical areas [16] and Mediterranean regions [17].

This work is focused on a new cool roof generation, characterized by high-reflectance coatings properly added with pigments that create the so called cool colors [18–20], that is colored surfaces with a high reflectivity in the infrared range of the solar spectrum

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[21,22]. Recent studies on acrylic coatings [23,24] highlighted that not only the coating but also the substrate is crucial for the achievement of an adequate solar reflectance. Moreover, it was found that the use of a ceramic support for both clay roof tiles [24,25] and traditional porcelain stoneware tiles [26,27] can provide very high solar reflectance over the whole solar spectrum and high durability against time.

In this work, an innovative approach is tested to achieve roof tiles with high capacity of rejecting solar radiation. It consists of using a cool-colored red tile with common brick (terracotta) color but relatively high solar reflectance, coupled with a thin insulating layer attached below the tile and made of a silica-gel super-insulating material. An aluminum foil with very low thermal emittance is also applied below the insulating layer to act as radiant barrier. Along the perimeter of each tile, line brushes are attached in order to enclose an almost sealed air space between the aluminum foil and the roof slab onto which the tile is installed. The brushes allow sealing the air space perimeter when the tile is supported on wooden battens. Terracotta tiles are acknowledged to be the finishing layer with underneath ventilation, but the adopted brushes allow sealing the ventilation layer and exploiting the resulting airspace for thermal insulation, also thanks to the radiant barrier provided by the aluminum foil. This can largely offset the loss of the weak cooling effect given by underneath ventilation in summer, while it is however helpful in winter to control heat loss. In fact, a layer of such composite tiles can provide a strong resistance to heat flow through the roof slab below thanks to the combined action the insulating layer and the air space. The contribution of the cool color coating is added in summer, further limiting building overheating and, in combination with that, the negative effects of urban heat island.

The proposed composite tile is intended for installation on uninsulated or poorly insulated roofs with inhabited spaces below by simply replacing the existing tiles. Thanks to the negligible increase of thickness, the tile layer can be installed onto an existing roof, for instance the sloped tile roof of an historical or traditional building, with no need to modify the roof height and structure, and thus the metal gutters and the other finishing elements that are usually present at the roof edges or around skylight windows. As a results, an increase of roof insulation is achieved not far from that provided by a much more invasive installation of a thick insulation layer, at the same time obtaining a shield against solar radiation more effective than that provided by the cool color coating alone.

The behavior of the developed tile is theoretically and experimentally investigated in this work, making a comparison with a common tile with the same brick color. Performance parameter such as solar reflectance, thermal emittance, and thermal conductivity are measured. Moreover, an experimental test rig has been set up.

2. Materials and methods

Experimental data were collected using two painted clay roof tiles. One of the tiles has been coated by a solar reflective brick red paint with solar reflectance $\rho_{sol}=0.46$, the other one by a standard paint with the same color but $\rho_{sol}=0.22$. A white basecoat with high solar reflectance has also been applied to the substrate material before the solar reflective cool color coating in order to exploit the selective transparency of the coating, if any, and thus further enhance ρ_{sol}. This approach was proposed in [28] and tested in previous work [23,24].

The solar reflectance was measured by means of a Devices and Services SSR solar reflectometer [29] compliant with the ASTM C1549 standard test method [30], using irradiance spectrum E891BN. The cool colored tile and the standard one were placed onto two battens mimicking the typical supports for such roof tile. A 2 cm airspace was thus created between the tile and the base below, consisting of a thick polystyrene panel (Fig. 1). A T-type thermocouple was placed below the tile, close to its center, to measure the temperature on the bottom surface of the airspace. In order to control the experimental conditions, another thermocouple was used to track the evolution of the room temperature during the measurement session. The temperature on the tile surface was also measured by a FLIR T-640 infrared camera [31]. Moreover, a black painted aluminum disc with known infrared emittance and an embedded thermocouple was placed in the field of view of the instrument, properly shielded from the lamp light, in order to compare the temperature measured by the thermocouple and that measured by the infrared camera, and thus to detect possible drifts of the surface temperature measurements.

All thermocouples were connected to a Pico TC-08 USB thermocouple data logger [32]. Four halogen lamps were placed over the sample and oriented in order to provide an estimated total irradiance of 870 W/m^2, measured by a Delta Ohm HD 9221 radiometer [33]. Since the instrument is sensitive only in the visible and near infrared range (450–950 nm), the total irradiance value was extrapolated from the measured one by taking into account the sensitivity curve of the instrument, the blackbody spectrum of the lamp filament at its nominal temperature of 4000 K and the transmittance spectrum of the quartz glass protecting the lamps. The obtained

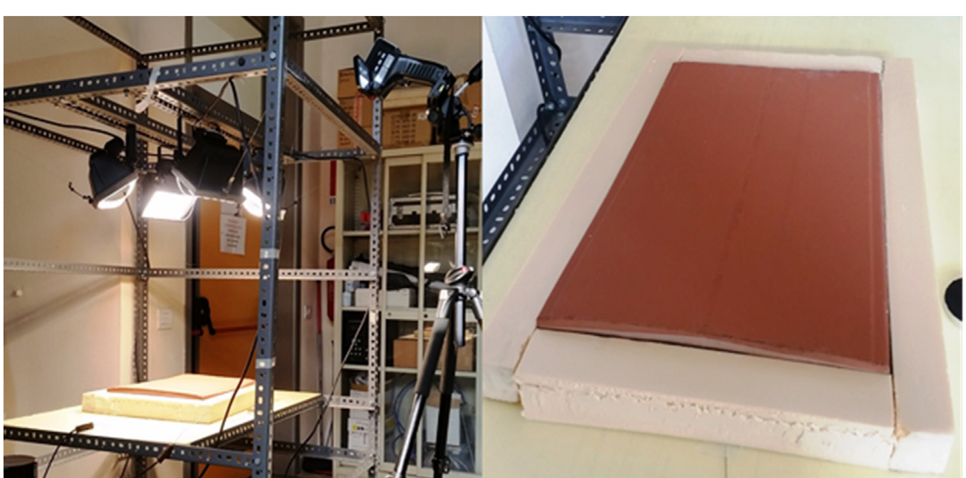

Fig. 1. Experimental setup.