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Cool products for building envelope – Part I: Development and lab scale testing

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Abstract

The paper describes the methodology followed for the development of new cool products in order to widen the range of existing solutions both including coloured (even dark) materials and extending the application also to building vertical components. Cool coloured ceramic tiles and acrylic paints for façades and roof membranes have been developed and tested at lab scale. Spectral reflectance measurements have been performed demonstrating a significant improvement of reflectance in the Near InfraRed (NIR) range (up to +0.40) while keeping dark colour and high absorbance in the visible. The development of new products has been also oriented to the improvement of durability properties, being this aspect of relevance for high reflecting materials that have to keep their cooling properties over the time. While ceramic tiles naturally offer superior resistance to outdoor ageing, a significant increase of biological growth resistance has been achieved also for roof membranes by including ZnO nanoparticles. The approach followed by the authors aimed at delivering products, that besides having higher NIR reflectance, were capable of satisfying industrial and market requirements being compatible with standard manufacturing processes and offering additional functionalities. A complementary paper will be dedicated to the extensive experimental and numerical evaluation of new materials' thermal performances.

Keywords: Cool roof; Solar reflectance; Cool ceramics; Cool paint; Nanotechnology; Urban Heat Island

1. Introduction

Buildings account for about 40% of total energy demand in Europe (Pérez-Lombard et al., 2008; European Commission, 2010) and a large fraction of this energy is consumed for space conditioning (HVAC systems). During summer, cooling energy consumption represents a major issue for Mediterranean countries and its demand is expected to further raise also as consequence of global warming (Isaac and Van Vuuren, 2009).

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Nomenclature

a^*	red/green value in CIE $L^*a^*b^*$ colour system	R_{VIS}	visible reflectance
b^*	yellow/blue value in CIE $L^*a^*b^*$ colour system	SRI	Solar Reflectance Index
CCAP	Cultural Collection of Algae and Protozoa	UHI	Urban Heat Island
CRRC	Cool Roof Rating Council	y	score of the surface coverage in the algae test
ECRC	European Cool Roof Council		
$I(\lambda)$	spectral hemispherical solar irradiance [W/m^2]	*Greek symbols*	
I_{tot}	total solar irradiance [W/m^2]	α	asymptotic maximum score in the algae test
L^*	lightness in CIE $L^*a^*b^*$ colour system	δ	time of inflection point in the algae test [day]
LEED	Leadership in Energy and Environmental Design (US green building council)	ΔE	colour difference
NIR	Near InfraRed	ε	slope at the inflection point in the algae test [day^{-1}]
R_{SOLAR}	solar reflectance	λ	wavelength [nm]
R_{NIR}	NIR reflectance	$\rho(\lambda)$	spectral reflectance

A promising and cost-effective solution is represented today by the so called cool materials that reflect a large amount of incident solar radiation and emit the absorbed energy back toward the atmosphere. Akbari et al. (2009) estimated that increasing the roof albedo worldwide from 0.15 to 0.25 can cause a CO_2 offset of 24 Gt. Rosenfeld et al. (1998) calculated a reduction of peak power up to 25 GW in the entire US corresponding to about 5 B$ of savings. Simulations of residential buildings under various climatic conditions estimated potential reduction of peak cooling demand in air-conditioning of 11–27% (Synnefa et al., 2007b). Significant improvements have been demonstrated for different Mediterranean regions like Spain (Boixo et al., 2012), Greece (Synnefa et al., 2012) and Italy (Romeo and Zinzi, 2011).

Together with the decrease of cooling energy consumption and the improvement of indoor comfort, cool materials are very promising for the mitigation of Urban Heat Island (UHI) effect. Highly absorbing surfaces such as those traditionally used for roofing and pavement systems are in fact among the major responsible for UHI effect determining an increase of air temperature of several degrees on densely urbanized areas. This phenomenon has been analyzed by many researchers and differences in temperatures up to 8–10 °C with respect to the surrounding environment have been measured in large Mediterranean cities like Barcelona (Moreno-Garcia, 1993) and Athens (Livada et al., 2002). The use of highly sun reflecting materials can significantly contribute to mitigate this effect by reducing the solar energy effectively absorbed by buildings (Synnefa et al., 2008).

Currently most of the cool roof solutions are based on white or light coloured materials that are often discarded when aesthetic appeal is a priority or because of some local codes regulating exterior building appearance in historical centres. A coloured surface, especially if dark, absorbs by nature a large amount of visible radiation resulting significantly warmer than the corresponding white surface. However, considering that more than 50% of the sun energy is emitted in the Near InfraRed (NIR) range, a large potential for improvement is expected also for coloured materials. A cool coloured surface is thus characterized by a spectral selective behaviour with high absorbance in the visible ($\lambda < 700$ nm) and in the mid IR (i.e. high thermal emittance) and high reflectance in the NIR range (700 nm $< \lambda <$ 2500 nm). Many researchers have already tackled this issue proposing methods for developing different cool coloured roof materials (Levinson et al., 2007, 2010a; Synnefa et al., 2007a). Most of these solutions are based on the application of NIR reflecting pigments (Levinson et al., 2005) on traditional substrates or on the use of NIR transparent topcoats on highly reflecting basecoats. Levinson et al. (2010a) presented 48 cool prototypes of concrete tiles and asphalt shingles with various shades of red, brown, green and blue and with solar reflectance ranging from 0.18 to 0.57. Using a similar approach, coated steel and glazed clay tiles with NIR reflectance up to 0.85 have been developed (Levinson et al., 2007). Some of these technological solutions have already been implemented into effective commercial products as reported in the CRRC and ECRC rated databases (CRRC, 2013 and ECRC, 2013). An increasing interest has risen in the last few years also toward other product categories not yet considered as cool materials. Ferrari et al. (2013) have recently started investigating on cool porcelain ceramic tiles trying to optimize the engobe composition and thickness for maximum reflectance. Revel et al. (2013) extended this concept also to non-white materials obtaining a series of brown tiles with increased solar reflectance.

Besides the aesthetic value given by the colour shade, an important issue concerning cool materials on which many researchers are currently focusing is represented by the effect of natural ageing on thermal performances (Revel et al., 2013; Sleiman et al., 2011). Both in the case of coloured or white surface, a cool material is required to keep the initial solar reflectance over the time. Most authorita-