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Cool products for building envelope – Part II: Experimental and numerical evaluation of thermal performances

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Abstract

Cool materials have a large potential as cost-effective solution for reducing cooling energy consumption in hot summer and mild winter regions like Mediterranean countries. A previous paper has described in detail the development of cool coloured ceramic tiles, acrylic paints and bituminous membranes for the building envelope taking into account both roof and façade application. This paper proposes an experimental and numerical approach for evaluating thermal performances of these materials on calibrated middle scale units and the energy impact on real buildings. This twofold analysis aims at describing a method that can help manufacturers to accurately compare new products against existing ones taking into account also new potential applications (e.g. building façades). Five dedicated test cells have been realized in Algete, near Madrid, fully instrumented and calibrated before being covered with traditional and cool systems of the same colour. Thermal performances have been then monitored during summer 2012 and May 2013 showing a net reduction of heat flux through the building envelope (up to 50% of peak value) and wall temperature (up to 4.7 °C) in the case of cool materials. An uncertainty analysis was also performed to validate results. In parallel with the testing campaign a 3D numerical model of the mock-up has been implemented and fine-tuned with experimental data. This model has been then used as virtual scenario on which coverings with different radiative properties can be accurately evaluated and compared. For a full characterization of new materials complementary simulations have been performed with the ESP-r software. Yearly cooling energy reductions ranging from 0.6 to 3.5 kW h/m^2 have been estimated on different European localities. This preliminary study also demonstrates how cool façades can have a positive impact on yearly energy savings especially in the case of multi-storeys buildings and hot climates. The results shown in the paper have been achieved within the EU project COOL-Coverings aiming at developing new cool coloured products for the building envelope.
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Keywords: Cool roof; Solar reflectance; Mock-up; Measurement; Numerical model

1. Introduction

An effective way to reduce the solar heat gain and cooling energy demand in buildings is to increase the amount of sun radiation that is reflected by the envelope components (both opaque and transparent ones) thus reducing the surface temperature. A cool material is characterized by an enhanced capability of reflecting solar energy (high solar reflectance) and emitting the absorbed heat back towards the atmosphere (high thermal emittance). Cooling the building envelope generates many

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Nomenclature

a^*	Red/green value in CIE $L^*a^*b^*$ colour system	*Greek symbols*	
ACH	Air Change per Hour	ΔE	Colour difference
b^*	Yellow/blue value in CIE $L^*a^*b^*$ colour system	λ	Wavelength (nm)
IR	InfraRed		
L^*	Lightness in CIE $L^*a^*b^*$ colour system		
NIR	Near InfraRed		

direct and indirect benefits for the building owner and the environment (Akbari et al., 2009; Rosenfeld et al., 1998): (i) reduction of cooling energy demand and CO_2 footprints, (ii) reduction of electricity peak loads, (iii) improvement of indoor thermal comfort for unconditioned spaces, (iv) mitigation of Urban Heat Island phenomenon and (v) reduction of thermal stress with consequent enhancement of material durability. Significant progress has been made in the last years both from the technical and the policy side (Synnefa and Santamouris, 2012b; Akbari and Matthews, 2012) and a wide range of cool roof solutions is now available. One of the most challenging technological issues is to obtain surfaces that are dark in colour and reflect sun energy at the same time staying cooler under sun exposure. This objective can be achieved by designing selective materials that are highly absorbing in the visible range and highly reflective in the NIR (Near InfraRed) range where the sun emits more than 50% of its energy. Several researchers have worked on this topic obtaining different coloured roof products (e.g. clay tiles, shingle and single ply membranes, metal roof) that exhibit significantly higher solar reflectance than colour matching standard materials (Levinson et al., 2007a, 2010; Synnefa et al., 2007a; Revel et al., 2013).

In the Part I of the paper (Revel et al., 2014) cool coloured ceramic tiles, acrylic paints and bituminous membranes for the whole building envelope (both roof and façade) have been developed and relative manufacturing processes optimized for industrial scale production. These materials show a net increment of NIR reflectance while keeping similar properties in the visible range with respect to conventional coatings. In this paper an experimental and numerical methodology for the evaluation of their thermal and energy performance is discussed. Several studies were presented in literature to demonstrate the applicability and performances of cool materials on real buildings (Santamouris, 2012; Synnefa et al., 2007b; Boixo et al., 2012; Akbari and Konopacki, 2005b). The large number of variables like climatic conditions, building type, insulation level, user behaviour and internal loads make this analysis very complex considering also that the heating penalties during winter can play an important role in the total yearly energy balance. Numerical models based on transient simulation tools (e.g. TRNSYS, DOE-2, 2002, EnergyPlus, 2013, ESP-r, 2005) allow to estimate energy savings on test cases of different complexity and under different conditions.

Despite the large potential in exploring many test cases in a cost-effective way, simulation results always rely on the correctness of the input data and on the effectiveness of model assumptions. Simplified numerical models need therefore to be supported and validated by experimental activities on which the effect of cool materials is directly measured on real buildings.

Many field studies have been documented in literature and different building types (Parker et al., 1995; Akbari et al., 1997, 2005a; Konopacki and Akbari, 2001; Pisello and Cotana, 2014) and scaled prototypes (Simpson and McPherson, 1997; Akbari, 2003; Levinson et al., 2007b; Shen et al., 2011) have been continuously monitored to demonstrate the impact of cool technologies on real applications. Parker et al. (1995) analysed eight occupied homes in Florida measuring a reduction of air-conditioning energy from 2% to 43% with an average drop in space-cooling of 7.4 kW h/d (19% with respect to the base case). Akbari et al. (2005a), monitored six California buildings (a retail store in Sacramento, an elementary school near San Diego and a four-building cold storage facility in Reedley) showing savings in average conditioning energy up to 72 W h/m^2/d (52%).

One of the most commonly used experimental method consists in applying cool solutions to existing buildings with low reflective (dark) roof and to compare thermal performances before and after the application of a cool roof material (usually white). Following this approach, Akbari et al. (1997) analysed three test cases in Sacramento, California (one residential building and two school bungalows) on which different roof coatings with albedo ranging from 0.08 (brown) to 0.79 (white) were applied. Reduction of peak cooling demand up to 0.57 ± 0.06 kW was measured in the case of white paint corresponding to cooling energy savings up to 40–49%. A similar approach has been systematically followed by other researchers demonstrating the effectiveness of highly reflecting coatings (light coloured) in reducing energy demand for different building typologies and climates (Akbari et al., 2005a; Synnefa et al., 2012a, Bozonnet et al., 2011; Kolokotsa et al., 2012; Romeo and Zinzi, 2013; Kolokotroni et al., 2013).

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