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Acrylic white paint of industrial sector for cool roofing application: Experimental investigation of summer behavior and aging problem under Mediterranean climate

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ABSTRACT

The paper proposes a complete experimental characterization of an acrylic white paint, widespread in the field of household appliances or automotive sector. This paints has been already studied by means of in-lab tests; results have suggested that it is suitable for cool roof application.

In this study, the results of a measurement campaign are discussed; it has been carried out by means of test-room of the University of Sannio, in Benevento city, under Mediterranean climatic conditions starting from the summer 2016 until the summer 2017. In detail, the in-field monitoring concerns: all data for describing indoor and outdoor climatic conditions; the measure of solar reflectance at start and after one year from paint's application; the indoor and outdoor surface temperatures, the heat flux; optical investigations in visual and infrared field. The proposed paint has been compared with a commercial cool roof product and with a polished aluminum varnish in term of improvement respect to traditional dark bituminous membrane. Also the in-field aging effect is studied to compare degradation of proposed paint and commercial cool paint.

Data elaborations bring to interesting conclusions; first of all, the in-field performance of acrylic paint is comparable to cool product and it is better than aluminum paint. Proposed product shows very fast drying, good gloss and appearance, lower application time and positive economic analysis. However, the aging is faster with in-field reduction of solar reflectance of around 20–25%. It could be due to application technique and to adopted product to favor the adhesion. This makes suitable other researches also for evaluate the application of a protective gloss that could assure greater durability than traditional product.

1. Cool roofing materials: characterization and performance

To counterbalance the urban heat island phenomenon, technologies aiming to increase the albedo of cities and the use of vegetative appear to be very promising (Santamouris, 2014). Some actual researches tend to use highly reflective white coatings and infrared reflective colored pigments to increase the albedo of the pavements surface and also color changing paints (Santamouris, 2013). Among other techniques the adoption of evaporative-cooling roof can be cited. Recently, Zhang et al. (2017) have proposed a multivariate nonlinear approach for modelling and analyzing the influence of evaporation on roof thermal performance. Considering data of Guangzhou, China, they have shown that evaporation beginning at 11:00 can reduce the external surface temperatures of a horizontal roof and 30°-inclined east-sloping and west-sloping roofs by up to 11.3 °C, 10.7 °C, and 9.8 °C, respectively, from those of a non-evaporative roof.

Considering the aim of this paper, a focus has been done on "cool materials" for opaque building envelope that are increasingly spreading during the recent years, thanks to positive effect in term of energy saving, indoor thermal comfort as well as for the benefits at urban scale (Synnefa et al. 2006, 2011). These are considered a passive radiative cooling technique (Hernández-Pérez et al., 2014; Lu et al., 2016), because during the day lower amount of solar radiation is absorbed; thus the surface temperature is kept lower and during the night there is a faster radiative cooling (Geetha and Velraj, 2012).

When cool materials are applied on roof, the solution is called "cool roof" (Santamouris, 2014). The European cool roofs council (ECRC, 2017) defines the "cool roof" as the roofing system able to reject solar heat and keep surfaces cooler under the sun. This is due to the properties of the materials used, which reflect the solar radiation (high solar reflectance, SR) and release the heat they have absorbed (high infrared emittance, ε). These proprieties give the material the ability to reflect a

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Nomenclature

AV	Acrylic Velox paint
BM	bituminous membrane
CP	California-P paint
DSR_{Mm}	difference between maximum and minimum SR value
DST	decrease of surface temperature [°C]
ε	thermal emissivity [–]
GSR	global solar radiation on horizontal plane [W/m^2]
k_t	hourly clearness index [–]
NIR	near infrared
PA	POLYVERALU paint
SR	solar reflectance[%]
SRI	Solar Reflectance Index [%]
T_a	mean air temperature [°C]
T_in	mean indoor air temperature [°C]
T_out	mean outdoor air temperature [°C]
T_s	surface temperature [°C]
U	thermal transmittance value [W/(m^2 K)]
RH	relative humidity [%]

large amount of solar radiation, and to be cooler if compared to conventional products with same color (Zinzi, 2016; Costanzo et al., 2016). In this case, some other benefits can be recognized as: increment of roof lifetime, reduction of thermal solicitations for materials below the external covering (Santamouris et al., 2011), low investment cost and not invasive interventions without structural modification (Ferrari et al., 2016).

The definition of a cool roof product is not univocally given; for example ENERGY STAR (ES, 2007) qualified products if for low slope roofs these have an initial SR ≥ 0.65 and after 3 years SR should be higher than 0.50. Moreover, according to last version of LEED protocol (2017) a roofing material must have an initial SRI of 39 or higher for steep slope roofing and a SRI value of 82 or higher for low slope roofing. It is defined also the limit value of SRI for 3-year aged roof coatings: 32 or higher for steep slope roofing and 64 or higher for low slope roofing. Otherwise, California's Title 24 Building Energy Efficiency Code classifies as cool roof those that meet 0.70 reflectance and 0.75 emittance (APEC, 2011).

Reflective products for roof can be found on the market as simple coating or paintings, membranes that can be pre-fabricated sheets (single-ply membranes) or liquid applied membranes, metal roofs, shingles, and tiles (Pisello, 2017). The coating type consists of acrylic paints, elastomeric or cementitious (Santamouris et al., 2011), with or without reinforcing fibers. Acrylic coatings can be thermoplastic or thermosetting. In addition, they can be applied in organic solvent borne, waterborne, powder or radiation-curable formulations. Usually, for cool applications, waterborne acrylic coatings are used. They are solid, plastic-like synthetic materials that are dispersed as microscopic particles in water. When the liquid evaporates, the microscopic particles of latex binder and pigment that remain on the painted surface fuse and bind the pigment into a continuous, flexible film that will be water resistant when dry. For cool product, SRI is near 105.

However, cool roof can be obtained covering a substrate with a pigmented coating, transparent in the infrared range. Cool materials are not only natural or artificial white material, because there are also colored reflective products (Synnefa et al., 2007a, 2007b). The non-white cool materials, characterized by the addition of reflective colored pigments, have the same spectral reflectivity of colored materials in the visible part of solar spectrum, but an higher spectral reflectivity in the near-infrared range (Synnefa et al., 2007a, 2007b; Santamouris et al., 2011). Briefly, the global reflectivity of these materials is higher than the conventional ones of the same color (Uemoto et al. 2010; Synnefa et al. 2007). About this topic, Synnefa et al. (2007a, 2007b), monitoring 14 different reflective paintings, have underlined a reduction between 2 °C and 4 °C of surface temperature. Levinson et al. (2007) in order to obtain blue and black NIR-reflective coatings, have applied a NIR-transmitting layer of color over an opaque and highly reflective white basecoat. For metal or glazed clay-tile, the application of cool topcoat allows to reach values of NIR reflectance respectively of 0.50 and 0.75. While for gray-cement concrete tiles NIR reflectance becomes more than 0.60.

Single-ply roofs are flexible or semi-flexible roof membranes typically constructed of rubber or plastic materials. Single-ply membranes can be generally categorized into two groups – thermosets and thermoplastics. Thermoplastic membrane systems are similar to thermoset systems, but are comprised of PVC (Polyvinyl Chloride) or TPO (Thermoplastic Polyolefin) or similar materials instead of rubber. In this case SRI varies between 100 and 110. Liquid membranes are monolithic, fully bonded, cold applied Polyurethane coating which is applied either by roller or spray. Reference value for SRI is 105.

Roof shingles are made of various materials such as wood shingle, slate shingle, cement, bitumen-soaked paper covered with aggregate (asphalt shingle) or ceramic. Tiles usually are made of clay, natural stone, metal (see metal roofing) or concrete. For instance, Ferrari et al. (2016) have tested a cool-colored red tile with common brick (terra-cotta) 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.

Metal roof is a roofing system using metal sheets or tiles typically pre-coated. Light colours with special pigments which allow them to behave similarly to much lighter colours.

Recently, directional reflective materials (DRMs) have been developed. DRMs are innovative products that reflect sunlight during summer and absorb sunlight during the winter (Akbari and Touchaeili, 2014). However, also according to Santamouris (2014), the future of cool materials for roof applications are the reflective materials with nano-technological additives or PCM.

According to the aim of this paper, the following section is dedicated to description of techniques for characterize cool properties as well as advantages and criticalities of cool roof adoption in Mediterranean climate.

1.1. Characterization and performance

The solar reflectance of opaque materials is the fraction of incident solar radiation that is reflected from an irradiated surface. Unless given for a specific wavelength (spectral reflectivity), it refers to the entire spectrum of solar radiation. The attitude to reflect is not only determined by properties of the surface itself (such as rugosity, impurities), but also by the spectral and angular distribution of solar radiation that reaches the surface (Akbari and Touchaeili, 2014). The thermal emissivity (or thermal emittance) indicates, at a given temperature, the ability of a surface to release away the absorbed heat. It is calculated as the fraction between thermal radiation emitted by a surface and the maximum theoretical emission at the same temperature (those one of the black body). For building products, thermal emittance measurements are taken for wavelengths in the infrared, thus it is named also infrared emittance. A combined index is often used to determine the overall ability to reflect solar heat and release thermal heat taking into account also convective cooling effects; it is the Solar Reflectance Index (SRI) calculated cording to ASTM E1980 Standard (ASTM, 2011). It measures the measures the relative steady-state temperature of a surface with respect to the standard white (SRI = 100) and standard black (SRI = 0) under the standard solar and ambient conditions.

According to the application, several methods and instrumentation