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Aging of roof coatings. Solar reflectance stability according to their morphological characteristics

Noelia L. Alchapar *, Erica N. Correa

INCIHUSA, Instituto Ciencias Humanas Sociales y Ambientales (Institute of Environmental and Social Sciences), Laboratorio de Ambiente Humano y Vivienda (Human Environment and Housing Laboratory), (CONICET – CCT-Mendoza), CC. 131, 5500 Mendoza, Argentina

HIGHLIGHTS

- Solar reflectance stability of roofing materials was evaluated according to its formal characteristics.
- Thermal performances of roof tiles are more susceptible to aging than the roof paint.
- Solar Reflectance Index of aged roofing materials decreases up to 37%.
- Color and composition have more influence over thermal behavior in new materials.
- Color and finish have more influence over thermal behavior in aged materials.

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ABSTRACT

Increasing solar reflectance on roofs is an efficient strategy for urban cooling. The aim of this study is to evaluate how the passage of time affects the thermal behavior of 19 roof tiles and roof paint. The impact of aging is quantified by the change in the Solar Reflectance Index over three years. The results show that the roof coatings evaluated tend to increase the surface temperature between 3.5 °C and 24 °C. The main morphological characteristics that impact the thermal performance of new materials are: color, composition and finish; while for aged materials are: color, finish and shape.

1. Introduction

The building envelope is responsible for the most significant loads that affect cooling energy use [1]. All materials that make up the building envelope have physical properties that determine the transfer of heat: conductivity, density and specific heat along with the optical properties -albedo and thermal emittance-. The last two properties are superficial dynamic properties, which can change over time.

Materials with high solar reflectance or albedo and high thermal emittance (cool materials) stay cool in the sun. They reduce the demand for energy for cooling buildings, which increases in the summertime for comfort in an unconditioned building [2]. Akbari and Matthews [3] and Akbari et al. [4,5] found that using reflective materials, both roof and pavement albedos can be increased by about 0.25 and 0.15, respectively, resulting in a net albedo increase for urban areas of about 0.1. On a global basis, they estimated that increasing the world-wide albedos of urban roofs and paved surfaces will induce a negative radiative forcing on the earth equivalent to offsetting about 44 Gt of CO_2 emissions. Recent studies developed by Akbari et al. [6] estimated the long-term effects of increasing urban albedo surfaces. They reported that each increase of 0.01 of albedo in a square meter of surface produces a cooling effect of 3×10^{-15} K, which corresponds to a reduction of CO_2 emissions equivalent to about 7 kg.

The roof is the most important radiative component of the building since it favors radiative cooling [7]. Several studies have described the benefits of cool roofs with a high albedo as an effective passive strategy for cooling [14–16,17] and they have quantified the energy saved in different building types and climates [18–24]. Highly reflective tiles and paint have been developed and studied in the U.S. and Europe [8–12]. Since 1999 building energy-efficiency standards are widely used, including ASHRAE 90.1, ASHRAE 90.2, the International Energy Conservation Code and California's Title 24 have adopted cool-roof credits or requirements [13].

* Corresponding author.
E-mail address: nalchapar@mendoza-conicet.gob.ar (N.L. Alchapar).

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Nomenclature

ε	thermal emissivity	Tb	standard black surface (°C)
$\hat{a}$	Albedo or solar reflectance	Ts	Surface temperature (°C)
m	slope or rate of aging	Ts_1	initial surface temperature (°C)
MMA	Mendoza Metropolitan Area	Ts_2	surface temperature at second year (°C)
P	roof paint	Ts_3	surface temperature at third year (°C)
SRI	Solar Reflectance Index (%)	Tw	standard white surface (°C)
SRI_1	Initial Solar Reflectance Index (%)	ΔSRI_{Total}	difference between SRI_1 and SRI_3 values (%)
SRI_2	Aged Solar Reflectance (second year) (%)	Δt	time difference (day)
SRI_3	Aged Solar Reflectance (third year) (%)		
T	roof tile		

Nevertheless, recent researches carried out by Lawrence Berkeley National Laboratory and Oak Ridge Laboratory and the EPA [25–29] have shown that the high initial solar reflectance of a roof can be degraded by soot, dust, and sun exposure. Berdahl et al. [30] evaluated the weathering of roofing materials concerning their exposure to the elements, namely wind, sunlight, rain, hail, snow, atmospheric pollution, and temperature variations along with the consequent degradation over time.

Within this framework, the aim of this paper is to evaluate the effect of aging on the thermal performance of roofing materials and establish which features of these materials (finish, composition, shape and color) have more influence on thermal behavior. The thermal behaviors are represented by their Solar Reflectance Indexes (SRI), according to the method described by ASTM E1980-11 standards [31] over three years.

2. Materials and methods

2.1. Study area

The study was carried out in Mendoza City, Argentina. A representative sample of the Mendoza Metropolitan Area (MMA) containing 64 hectares, forming a grid of 8 × 8 street blocks, is evaluated due to the intensive use of materials in this high density area.

The characteristics of the roofs studied correspond with architectonic styles resulting from Spanish colonial traditions. Simultaneously, as a result of the incorporation of new tendencies in architecture, new shapes, compositions and finishes of materials have been adopted. Recent housing units built over the last few decades show that cement tiles have been more frequently used rather than the traditional clay tiles. They are predominantly dark tonalities and with varied shapes and finishes.

During the summer of 2010, we gathered the compositional percentages of each of the materials that make up the urban envelope. We took photographic records and made tables that characterized the surfaces of roofs, walls and floors of each of the plots contained in the sample.

In our study, the results from the materials assessed for roofing showed that 61% of the roofs are flat, while the remaining 39% are sloping roofs [32]. The superficial material applied for insulation on flat roofs is the asphalt membrane; whereas, tiles are used for sloped roofs.

Given that Mendoza is arid, flat roof coatings tend to dry out and break due to severe solar radiation, dirt and hail. We observed a widespread use of a special liquid membrane paint which protects and significantly improves the durability of the roofs.

Within the area evaluated, 43% of flat roofs have white paint over the membrane, 20% have terracotta paint over the membrane, and 8% have athermic paint over the membrane. The remaining 29% of flat roofs have left the membrane unpainted among other situations.

80% of sloped roofs are made of terracotta clay tile (french or colonial shape). The remaining 15% are black concrete [33] (see Fig. 1).

2.2. Selection and characterization of sample unit

19 types of roof coatings, available on the local market, were tested to determine how aging influences their thermal behavior and solar reflectance levels. Each material has different morphological characteristics (finish, composition, shape, and color).

The sample unit consists of 16 types of roof tiles with: (i) finish -*natural, enamel, antique, single and double glazed*-; (ii) composition -*clay and concrete*-; (iii) shape -*colonial, french, and roman*-; (iv) and color -*terracotta, gray, and black*-. Distinctively, 3 different types of roof paint were studied according to: (i) finish -*matte and glazed*-; (ii) composition -*athermic and waterproof*-, (iii) and color -*white and terracotta*- (see Table 1).

2.3. Calculation of Solar Reflectance Index (SRI)

In this work, we quantified the reflectance capacity of roof coatings by means of the Solar Reflectance Index (SRI). The SRI of each material is based on its albedo ($\hat{a}$), its thermal emittance (ε), and its superficial temperature (Ts) when exposed to the solar radiation at 13.00 hs. According to ASTM E1980-01 "Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces" [31]. SRI quantifies how hot a flat surface would get relative to a standard black – Tb – (reflectivity 5%, emittance 90%) and a standard white surface – Tw – (reflectivity 80%, emittance 90%). The calculation of this index is based on a set of equations

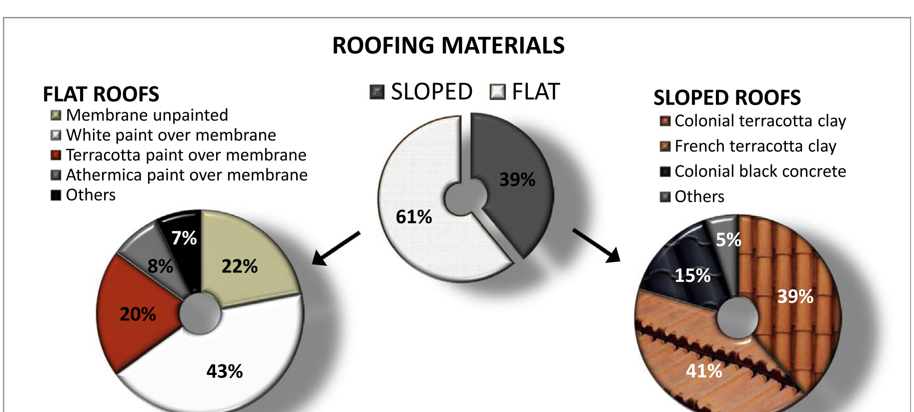

Fig. 1. Percentage of roofing materials in the study area.