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

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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].

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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

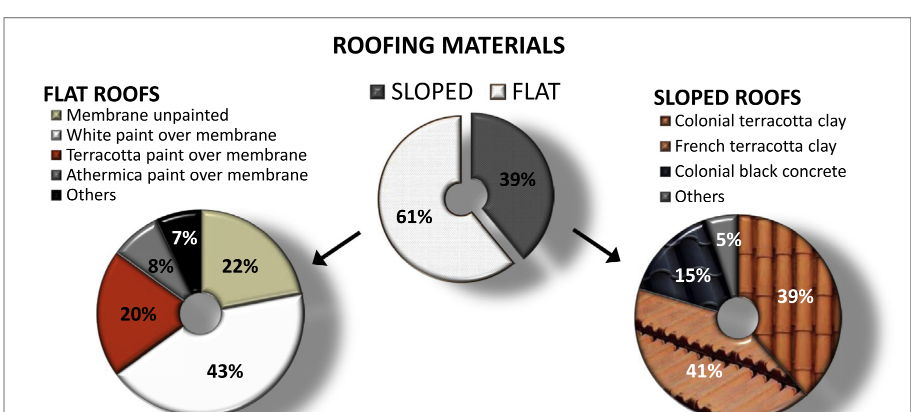
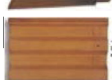
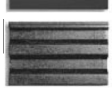
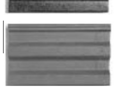
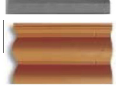
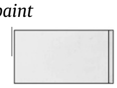
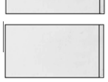
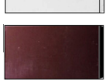


Fig. 1. Percentage of roofing materials in the study area.

Table 1
Characteristics of roofing materials according to codification (Cod.), detail (Det.), finish, composition (Comp.), shape and color.

Cod.	Det.	Finish	Comp.	Shape	Colors
Roof tiles					
T01		Natural	Clay	Colonial	Terracotta
T02		Natural	Clay	French	Terracotta
T03		Enamel	Clay	French	Terracotta
T04		Double glazed	Clay	French	Black
T05		Single glazed	Clay	French	Black
T06		Double matte	Clay	French	Black
T07		Single matte	Clay	French	Black
T08		Enamel	Clay	Roman	Terracotta
T09		Natural	Clay	Roman	Terracotta
T10		Antique	Clay	Roman	Terracotta
T11		Natural	Concrete	French	Terracotta
T12		Matte	Concrete	French	Black
T13		Acrylic	Concrete	French	Black
T14		Natural	Concrete	French	Gray
T15		Matte	Concrete	Colonial	Black
T16		Matte	Concrete	Colonial	Terracotta
Roof paint					
P01		Matte	Athermic	–	White
P03		Glazed	Waterproof	–	White
P04		Glazed	Waterproof	–	Terracotta

(ASTM 1980E-01) that require measured values of solar reflectance and infrared emittance for specific environmental conditions. From the definition of the SRI it is expected that very hot materials can actually have negative values and very cool materials can have values greater than 100 [34]. Several SRI calculators have been developed and available on line (ORNL SRI Calculator, LBNL Heat Island Group SRI calculator excel sheet, LEED's SRI Calculator) sheet, LEED's SRI Calculator) [35–37].

2.3.1. Measurement conditions

The thermal behaviors of tiles and roof paints were studied during summer seasons of 2011, 2012 and 2013. The samples were located on a 10 cm dense base of expanded polystyrene in the Regional Center of Scientific and Technical Research in the west area of the city (32°53′ latitude, 68°51′ western longitude).

2.3.2. Instrumentation

The environmental characteristics of days studied were recorded with ONSET Weather, HOBO® type and H21-001 model (operating range between 253 K and 323 K). The mobile weather station contained: HOBO S-THB-M002 61 temperature and relative humidity sensor, HOBO S-WSA-M003 wind speed sensor, HOBO S-WDA-M003 wind direction sensor, HOBO S LIB-M003 silicon pyranometer and HOBO S-GAP-CM10 barometric pressure sensor.

From the series of measurements registered, the reported data in Table 2 corresponds to 13.00 hs of the days whose meteorological variables presented typical conditions of the local climate, according to regulation ASTM 1980-11 [31].

In order to calculate the albedo ($\hat{a}$) of each sample, a CM3 Kipp & Zonen albedometer was used along with a pair of white and black masks over the 1 m^2 area surface, in conjunction with the method developed by Akbari et al. [38]. The spectral range of the albedometer is of about 285–2800 nm, with a maximum solar radiance of 4000 W/m^2. Its nominal sensitivity is of 1.5 10–6 V/Wm^{-2}. The indicated response time (95%) is 18 s.

The emittance (ε) was obtained according to regulation ASTM E1933–99a [39] through a temperature sensor with a type T thermocouple associated with data logger hobbo U12. The value of the radiant flux emitted by the material was compared to the data registered in an IR Fluke 568 thermometer with emittance adjustment. This way, the emittance of the material is that which coincides with the thermal measurements of the thermocouple and the IR thermometer.

The superficial temperatures (Ts) were registered on an IR Fluke Ti 55 camera, which detects infrared long wave radiation on a range of 7.5 to 14 µm within the electromagnetic spectrum. Thermal images register the radiant heat of each tile.

Concurrently, the surface temperatures of each material were measured and contrasted with type T thermocouples incorporated to a data logger LASCAL EL-USB-TC, which were registered every minute (see Fig. 2).

2.3.3. Aging of SRI

In order to quantify the response of the thermal behavior of the material over the passage of time, we used the followings formulates:

$$SRI_1 - SRI_2 = \Delta SRI_1 \tag{1}$$

$$SRI_2 - SRI_3 = \Delta SRI_2 \tag{2}$$

$$SRI_1 - SRI_3 = \Delta SRI_{Total} \tag{3}$$

where; SRI_1 = Initial Solar Reflectance Index (2011); SRI_2 = Aged Solar Reflectance (2012); SRI_3 = Aged Solar Reflectance (2013); ΔSRI_{Total} = Difference between SRI_1 and SRI_3 values.

Eq. (4) calculates the speed with which SRI level of a material degrades after three years of exposure:

$$m : \Delta SRI/\Delta t \tag{4}$$

where; m = slope or rate of aging; ΔSRI = difference of SRI levels; Δt = time difference.

In order to determine the range of stability of the SRI index, we evaluated the slope (m) of aged materials. The calculated slopes of all samples evaluated are between m: 2.33 and m: 12.33.

Based on this, we established that a material is stable when its slope (m) ranges between 2.33 and 5.67; moderate degradation when m oscillates between 5.68 and 9.0; and severe degradation when m ranges between 9.01 and 12.33. I.e.: $m \leqslant 5.67$ = Stable (Cat. A); $5.68 < m \leqslant 9.0$ = Moderate Degrade (Cat. B); $m > 9.01\%$ = Severe Degrade (Cat. C) (see Fig. 3).

3. Results

The results are presented in the following form:

Section 3.1: Assessment of thermal behavior and SRI of roof coatings in the first (3.1.1), second (3.1.2), and third period (3.1.3).

Section 3.2: Assessment of thermal efficiency of roof coatings according to their characteristics (finish, composition, shape, and color) at the first (3.2.1) and third years (3.2.2).

Section 3.3: Assessment of SRI stability due to aging, between periods (3.3.1) and according their characteristics (3.3.2).

According to the equations and parameters of regulation ASTM E1980-11 [31], the SRI of the roofing materials -tiles and roof paints-were obtained for the three measurement periods. The materials were analyzed whether they were: new (SRI_1), aged one year (SRI_2), aged two years (SRI_3) and their corresponding difference (ΔSRI_{Total}) (Table 3).

Table 2
Meteorological data for days studied.

Weather variables	Roof tiles			Roof paint		
	Mar 10, 2011	Feb 02, 2012	Jan 01, 2013	Jan 3, 2011	Dec 28, 2012	Dec 28, 2013
Solar radiation (W/m^2)	916	930	980	966	954	973
Air temperature (°C)	29.5	28	26	33	31	36
Relative humidity (%)	25	31.5	30	27.5	25	31
Wind speed (m/s)	2	1.3	1.3	0.8	1.1	0.9

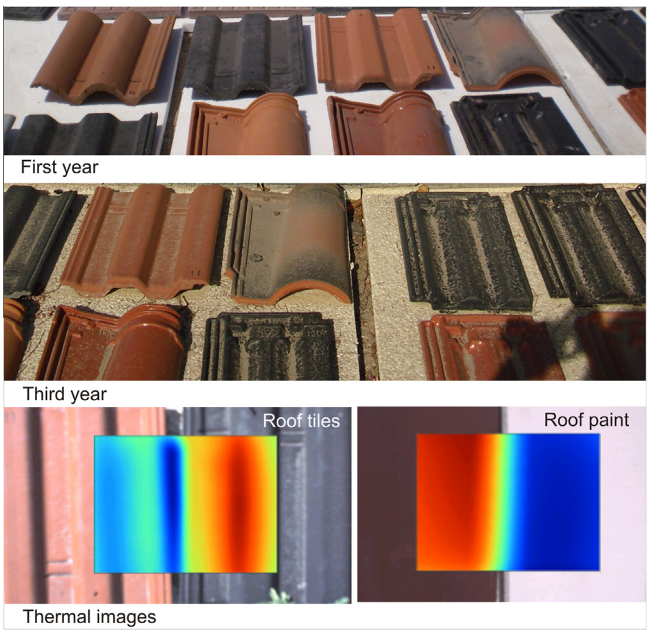


Fig. 2. Detail of roof coatings in the first and third years of expositions. Thermal images recorded with IR camera Fluke Ti 55.

3.1. Thermal behavior and SRI by periods

The following extreme values were obtained for each period:

3.1.1. First period (2011)

The tiles with higher initial SRI levels are: *Natural clay- colonial-terracotta -T01-* and *Enamel clay- roman- terracotta -T08-* with an albedo of $\hat{a} = 0.71$, surface temperature Ts_1 between 42 and 43 °C, and $SRI_1 = 90\%$. In contrast, the tile with the least favorable behavior is the *Matte concrete- french- black -T12-*, with a albedo $\hat{a} = 0.31$, surface temperature of $Ts_1 = 64$ °C and $SRI_1 = 47\%$.

Paint that demonstrates the best thermal behavior is *Matte athermic-white -P01-*. It has an albedo of $\hat{a} = 0.82$, surface temperature $Ts_1 = 41.5$ °C, and SRI_1 of 96%. The worst thermal behavior is shown by *Glazed waterproof-terracotta -P03-*. It presents an albedo of $\hat{a} = 0.61$, $Ts_1 = 59.5$ °C and $SRI_1 = 58\%$.

For new materials, we observed that there is little difference between surface temperatures and the SRI of the best paint and tiles (*T01* vs. *P01*). However, when comparing the least efficient materials (*T12* vs. *P03*), the difference can reach up to 4.5 °C. This shows the advantage of painting the roof with the appropriate materials.

3.1.2. Second period (2012)

The best tiles for this evaluation are: *Natural clay- colonial-terracotta-T01-*, *Enamel clay- french- terracotta-T03-*, and *Enamel clay- roman- terracotta-T08-*. With an $\hat{a} = 0.59$, 0.60, 0.59 respectively, $Ts_2 = 53$ °C and $SRI_2 = 73\%$ for the three materials. The lowest SRI percentage belongs to the *Acrylic concrete- french- black -T13-*, which has an $\hat{a} = 0.29$, $Ts_2 = 70$ °C, and $SRI_2 = 43\%$.

During this period, the highest SRI shown by paint is *Glazed waterproof white -P02-*. It has an $\hat{a} = 0.86$, $Ts_2 = 38$ °C, and $SRI_2 = 98\%$. The worst behavior again is shown by *Glazed waterproof terracotta -P03-*, with an $\hat{a} = 0.68$; $Ts_2 = 51$ °C; $SRI_2 = 73\%$.

3.1.3. Third period (2013)

The materials with the highest SRI levels after 3 years of exposure are: *Natural clay- colonial- terracotta -T01-* and *Enamel clay- roman- terracotta-T08-*, with an $\hat{a} = 0.42$, $Ts_3 = 64$ °C, and $SRI_3 = 54\%$. The tile which showed the least favorable behavior was *Matte concrete- french- black-T12-*, with $\hat{a} = 0.16$, $Ts_3 = 78$ °C and $SRI_3 = 29\%$ (see T01- T03- T08- T12 and T13 in Table 3).

The roof paint *Matte athermic white -P01-* is the coolest after three years; it has $\hat{a} = 0.78$, $Ts_3 = 46$ °C and SRI = 82.5%. The tile which showed the least favorable behavior is *Glazed waterproof terracotta -P03- $\hat{a} = 0.58$*, $Ts_3 = 63.5$ °C, $SRI_3 = 51\%$ (see P01–P02 and P03 in Table 3).

Therefore, the most efficient paint *-P01-*, after aging, is 18 °C cooler than the most efficient tiles *-T01* and *T08-*. Also, this paint has a SRI_3 28.5% higher than those tiles. As for the most inefficient options, the paint *-P03-* is 14.5 °C colder and has a SRI_3 22.5% higher than the hottest tiles (see P01 vs. T01 and T12 vs. P03 in Table 3).

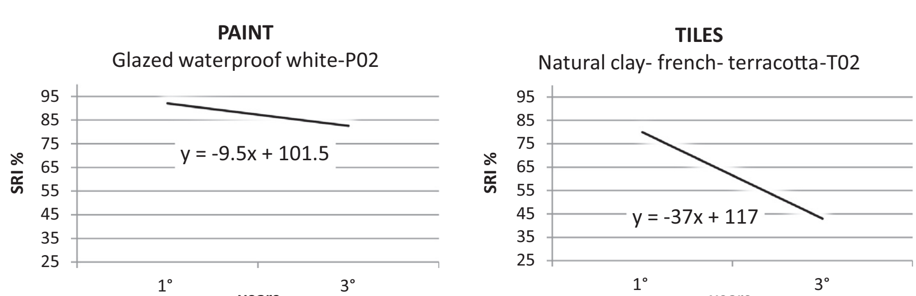


Fig. 3. Speed aging of SRI levels over time. Extreme cases: P02 paint (most stable material) vs. T02 tile (most degraded material).

Table 3
Enumeration of roof tiles (T) and roof paint (P). During the three periods of study (2011–2012–2013), with assigned codes; description; albedo ($\hat{a}$), surface temperature (Ts_1, Ts_2, Ts_3) in Celsius degrees; Solar Reflectance Index (SRI1, SRI2, SRI3) in percentages; total SRI difference (SRI1 – SRI 3 = ΔSRI Total), and slope (ΔSRI/Δ*t*).

Cod.	Description	2011			2012			2013			ΔSRI_{Total}	Slope	Cat.
		$\hat{a}$	Ts_1	SRI_1	$\hat{a}$	Ts_2	SRI_2	$\hat{a}$	Ts_3	SRI_3		$\Delta SRI/\Delta t$	
T01	Natural clay-colonial-terracotta	0.71	43	90	0.59	53	73	0.42	64	54	36	12.00	C
T02	Natural clay-french-terracotta	0.62	48	80	0.56	56	68	0.35	70	43	37	12.33	C
T03	Enamel clay-french-terracotta	0.64	47	81	0.60	53	73	0.40	66	49	32	10.67	C
T04	Double glazed clay-french-black	0.47	56	64	0.38	65	51	0.28	71	41	23	7.67	B
T05	Single glazed clay-french-black	0.41	58	59	0.38	66	49	0.26	74	35	24	8.00	B
T06	Double matte clay-french-black	0.41	58	58	0.37	66	48	0.21	77	29	29	9.67	B
T07	Single matte clay-french-black	0.43	57	60	0.40	65	51	0.26	74	35	25	8.33	B
T08	Enamel clay-roman-terracotta	0.71	42	90	0.59	53	73	0.42	64	54	36	12.00	C
T09	Natural clay-roman-terracotta	0.67	45	85	0.57	54	71	0.41	64	53	32	10.67	C
T10	Antique clay-roman-terracotta	0.55	51	72	0.55	55	68	0.37	67	48	24	8.00	B
T11	Natural concrete-french-terracotta	0.47	55	64	0.55	55	68	0.37	67	47	17	5.67	B
T12	Matte concrete-french-black	0.31	64	47	0.30	69	44	0.16	78	29	19	6.00	B
T13	Acrylic concrete-french-black	0.37	61	53	0.29	70	43	0.20	75	33	20	6.67	B
T14	Natural concrete-french-gray	0.65	46	82	0.57	54	71	0.38	66	49	33	11.00	C
T15	Matte concrete-colonial-black	0.46	56	63	0.30	69	44	0.20	75	33	31	10.00	C
T16	Matte concrete-colonial-terracotta	0.46	56	63	0.49	59	61	0.33	70	43	20	6.67	B
P01	Matte athermic-white	0.82	41.5	92	0.84	40	96	0.78	46	83	9	3.17	A
P02	Glazed waterproof-white	0.83	43	89	0.86	38	98	0.80	47.5	82	7	2.33	A
P03	Glazed waterproof-terracotta	0.61	59.5	58	0.68	51	73	0.58	63.5	51	7	2.33	A

Fig. 4 shows the SRI values according to materials during the three periods of measurement, in order to compare their reflectance with age.

Initially, the roof coatings analyzed showed a higher dispersion in their SRI values. They are grouped under an SRI_1 range of 92 to 47%. 94% of the evaluated tiles and 100% of the roof paint show an initial SRI_1 greater than 50% (see Fig. 4a). In the third period of aging, tiles are grouped in a SRI_3 range of 54–29%, which indicates that 80% of the materials initially considered efficient in their thermal behavior have worsened by 61% after three years. In contrast, the roof paint is grouped in a SRI_3 range of 7%and 9.5% after aging (see Fig. 4c).

In addition, Fig. 4 clearly demonstrates that albedo is the variable most affected by aging. Likewise, the surface temperatures of tiles increased with aging between 12 and 22 °C, while the roof paint increased surface temperatures between 4 and 4.5 °C (see Fig. 4c and Table 3).

3.2. Thermal efficiency of roof coatings according to their characteristics

We evaluate the thermal behavior (Ts) and Solar Reflectance Index (SRI) of materials according to the characteristics of the categorization established in Table 1 (finish, composition, shape and color) for new materials (Section 3.2.1) and for aged materials after three years (Section 3.2.2).

3.2.1. First year (Ts_1-SRI_1)

3.2.1.1. Contrasting finish. Terracotta *enamel* finish and black *glazed* finish are the most efficient for clay roof tiles. The worst thermic behavior is the *antique* finish. For example, if one analyzes the case of the *Clay roman terracotta tile* with the *enamel* finish *-T08-*, one sees a SRI_1 level up to 18% higher than the same tile with *aged* or *natural* finish-*T09* and *T10-*. The same applies to *-Ceramic french terracotta-* type tiles (see T02 vs. T03 in Table 3).

For black clay tiles, the *glazed* finish is 6% more efficient than the matte finish (see SRI values of T04 vs. T06 in Table 3). For the case of concrete composition roof tiles, the *acrylic* finish seems to improve thermal performance when compared to tiles that have a *matte* finish. I.e. *-Acrylic concrete- french- black -T13-* tile has a $SRI_1 = 53\%$, while the *-Matte concrete- french- black -T12-* has an $SRI_1 = 47\%$ (see T13–12 in Table 3).

Concerning roof paint, *glazed* finish (P01) is more efficient than *matte* finish (P02). Differences of 1.5 °C for the Ts_1 and 3% of SRI_1 were noted (see P01 and P02 in Table 3).

3.2.1.2. Contrasting composition. In most cases, *clay* tiles have a better thermal behavior than *concrete* tiles. This difference reaches significant values for colonial tiles in terracotta with a natural finish. For example, *-Cerámica natural colonial terracotta -T01-* performs better than *-Concrete natural colonial terracota-T11-*. Ts_1 difference between these two options is 12 °C and the difference in SRI_1 value is 26% (see T01 vs. T11 in Table 3). For paint, the *athermic* composition *-P01-* is the most efficient; it registers a Ts_1 of 41.5 °C and an SRI_1 equal to 92%.

3.2.1.3. Contrasting shape. According to the different shapes (see Table 1) with the same color and finish, the *colonial* form shows the best performance in terms of surface temperature. We recorded differences between 2 and 5 °C of Ts_1, and 5 and 10% of SRI_1 levels (see T01, T02 and T09 in Table 3).

3.2.1.4. Contrasting color. Thermal performance varies significantly with color. For clay tiles, the most efficient behaviors are observed in *terracotta*, while for concrete tiles, *gray* is the coolest color. For both compositions, *black* always shows the less efficient thermal performance.

The surface temperatures of terracotta range between 42 and 56 °C and SRI_1 levels of between 90% and 63% (see T01–T02–T03–T08–T09–T10–T11–T16 in Table 3) while black colored tiles range between 47 to 64 °C and between 64% and 56% in SRI_1 levels (see T04–T05–T06–T07–T12–T13 and T15 in Table 3). It is important to emphasize that light colors such as gray significantly improve the thermal performance of concrete tiles (see T11–T12–T14 in Table 3).

As regards roof paint, terracotta paint recorded the least efficient behavior with a Ts_1 of 59.5 °C and an SRI_1 of 58% while white paint showed the best behavior (see P02 vs. P03 in Table 3).

In sum, the characteristics that have a greater impact on the thermal performance of the roof coatings are: *color* and *composition*, followed by the *finish* and to a lesser degree the *shape*. *Color* may affect Ts_1 up to 18 °C and 35% of SRI_1 levels; the *composition* modifies Ts_1 up to 12 °C and 26% of SRI_1 levels; the *finish* alters

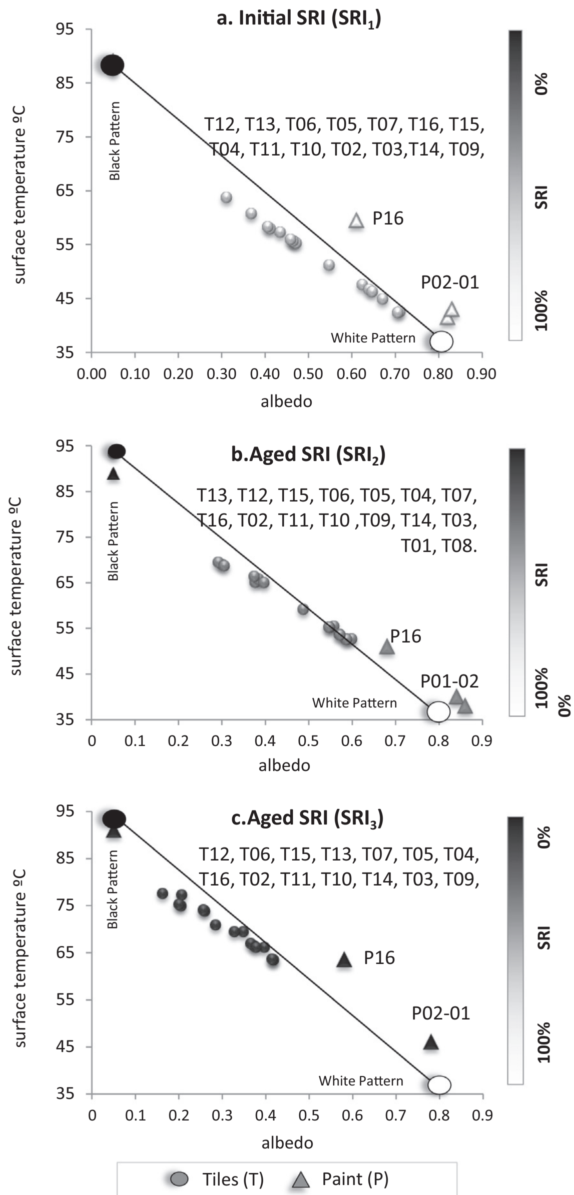


Fig. 4. Solar Reflectance Index of roof coatings by periods. a. Initial SRI (SRI_1). b. Aged SRI (SRI_2). c. Aged SRI (SRI_3) according to surface temperature (°C) and albedo.

Ts_1 up to 9 °C and 18% of SRI_1 levels; and the *shape* can modify Ts_1 up to 5 °C, and until 10% of SRI_1 levels.

The characteristic that has the greatest impact on the thermal performance of roof paint is: *color* followed by *finish* and then *composition. Color* may affect Ts_1 up to 16.5 °C and 31% of SRI_1 level. While, *finish* and *composition* can modify Ts_1 only up to 1.5 °C, and until 3% of SRI_1 levels.

3.2.2. Third year (Ts_3-SRI_3)

3.2.2.1. Contrasting finish. In aged clay tiles, the most efficient finish is *glazed*, then *enamel*. In aged concrete tiles, the most competent is the *acrylic* finish.

Specifically, for terracotta ceramic roof tiles, the *enamel* finish has the best behavior, its Ts_3 is up to 4 °C cooler and its SRI_3 level is up to 6% higher when compared to the other alternatives with identical characteristics but different finishes (see T08 vs. T09 vs. T10; and T02 vs. T03 in Table 3). While for roof tiles with the same composition but in *black* the differences are greater: those of glazed finish have a Ts_3 = 6 °C cooler and SRI_3 = 12% higher (see T04 vs. T06 in Table 3). In the case of concrete tiles, the *acrylic* finish improves Ts_3 by 3 °C and 4% SRI_3 levels (see T13 vs. T12 in Table 3).

For roof paint, the *glazed* finish is the most efficient. Nevertheless, the impact of the change is small: Ts_3 difference of 1.5 °C and 0.5% of SRI_3 (see P01 vs. P02 in Table 3).

3.2.2.2. Contrasting composition. Clay tiles are more efficient than *concrete*. For example, colonial terracotta tiles with a natural finish are 3 °C cooler and have SRI_3 levels 7% higher (see T01 vs. T11 in Table 3).

The athermic composition of roof paint is the most efficient. Ts_3 differences up to 1.5 °C and SRI_3 differences up to 0.5% were registered (see P01 vs. P02 in Table 3).

3.2.2.3. Contrasting shape. If we evaluate the performance of the tiles in the third year considering shape, we observe that *colonial* shape shows the best performance in terms of surface temperature and SRI levels. *Colonial* tiles demonstrated Ts_3 differences of up to 6 °C, and in SRI_3 levels up to 11% (see T01 vs. T02 in Table 3).

3.2.2.4. Contrasting color. For clay roof tiles, the most efficient color is *terracotta* and for concrete roof tiles is *gray*. *Terracotta* clay tiles are up to 13 °C cooler and have up to 25% higher SRI_3 levels (see T01 vs. T06). For the case of concrete tiles, the color *gray* presents difference of up to 12 °C in Ts_3 and up to 20% in its SRI_3 (see T11–T12–T14 in Table 3).

White roof paint is up to 18 °C cooler and has up to 31% higher SRI_3 levels when compared to the other color alternatives (see P02 vs. P03 in Table 4). In summary, color is the characteristic that modifies thermal behavior the most for first and third year coatings.

In roof tiles, *color* can change surface temperature up to 13 °C and SRI_3 values up to 25%. Another important feature is the *finish* that affects Ts_3 up to 6 °C and up to 12% of the value of SRI_3,

Table 4
Percentage (%) of roofing materials, according categories (A–B–C). Comparative analysis in the effect of morphological characteristics -finish, composition, shape and color-concerning the aging of SRI.

ROOF TILE				
	CAT.	A	B	C
FINISH	ACRYLIC		100	
	MATTE		67	33
	ANTIQUE		100	
	GLAZED		100	
	ENAMEL			100
	NATURAL		20	80
COMPOSITION	CONCRETE		67	33
	CLAY		50	50
SHAPE	ROMAN		33	67
	FRANCH		70	30
	COLONIAL		33	67
COLOR	BLACK		86	14
	GRAY			100
	TERRACOTTA		37.5	62.5
ROOF PAINT				
	CAT.	A	B	C
FINISH	MATTE	100		
	GLAZED	100		
COMPOSITION	ATHERMIC	100		
	WATERPROOF	100		
COLOR	WHITE	100		
	TERRACOTTA	100		

Cat. A: Stable; Cat. B: Moderated degradation; Cat. C: Severe degradation.

followed by that *shape* can modify Ts_3 up to 6 °C and up to 11% of SRI_3 levels. We found that *composition* affect surface temperature to a lesser extent, which can affect Ts_3 up to 3 °C and SRI_3 levels up to 7%.

For roof paint, *color* variation can change Ts_3 up to 18 °C and SRI_3 levels up to 31% while the *finish* and *composition* characteristics affect surface temperature only 1.5 °C and 0.5% SRI_3 level.

3.3. Stability or instability due to aging

In this section, the variation of the values of Solar Reflectance Index (SRI) of the material over time is analyzed. Comparisons are made in order to show how weathering impact on the thermal behavior of the materials.

3.3.1. Stability between periods (classification A, B or C)

By means of Eq. (3), the SRI_{Total} was obtained in order to determine that roof coatings are more resistant to aging. After three years, 56% of tiles have a moderated degradation (Cat. B), while the remaining 44% have a severe degradation (Cat. C). The tile which shows least modification in its SRI value between 2011 and 2013 periods (ΔSRI_{Total}), is the *Natural concrete- french-terracotta-T11-* with an decrease of 17% of SRI levels (Cat. B).

This contrasts with roof paint behavior, which stays 100% stable (Cat. A) after three years of exposure. *Glazed impermeable white-P02* and *Glazed impermeable terracotat-P03* roof paint show less alteration in SRI values, with differences of 7% between the 2011–2013 periods. Fig. 5 shows the 19 roof coatings evaluated, according to the stability of their SRI values. Cat. A (stable); Cat. B (moderated degrade); and Cat. C (severe degrade).

The results discussed in this study indicate that the application of tiles on roofs is not an efficient strategy for urban cooling because all roof tiles assessed suffer degradation: moderated (Cat. B) or severe (Cat. C) (see Fig. 5).

In the next section, in order to determine the degree of impact aging has for each of the morphological characteristics of the tiles (finish, composition, shape and color), the instability of the SRI will be evaluated for the first and third years.

3.3.2. Stability according to characteristics

3.3.2.1. Contrasting finish. To start, 80% of tiles with *natural* finishes presented severe degradation (Cat. C) decreasing their SRI index between 33% and 36% as a result of the aging process. The remaining 20% showed a moderate degradation (Cat. B). 100% of the *acrylic, glazed* and *antique* tiles had a moderate degradation of their SRI (Cat. B) (see Table 4).

3.3.2.2. Contrasting composition. After aging, the differences in SRI levels for the *clay* and *concrete* tiles were calculated.

In the case of *clay* tiles, 50% showed a severe degradation (Cat. C), and the remaining 50% registered a moderate degradation (Cat. B) of their SRI levels. 33% of *concrete* tiles had a severe degradation (Cat. C) and the remaining 67% had a moderate degradation (Cat. B) (see Table 4).

3.3.2.3. Contrasting shape. By separately analyzing each *shape*, it was observed that 67% of the *colonial* configurations had severe degradation (Cat. C) and the remaining 33% had moderate degradation (Cat. B). The *french* tiles registered 30% severe degradation (Cat. C), and 70% had moderate degradation (Cat. B). 67% of the *roman* tiles reached severe levels of degradation (Cat. C) and the remaining 33% had moderate degradation (Cat. B) (see Table 4).

3.3.2.4. Contrasting color. The color *gray* showed severe degradation (Cat. C). In the case of *terracotta* tiles, 62.5% demonstrated severe degradation, and the remaining 37.5% showed moderate degradation (Cat. B). 14% of *black* tiles registered severe degradation of SRI levels (Cat. C), 86% presented moderate degradation (Cat. B) (see Table 4).

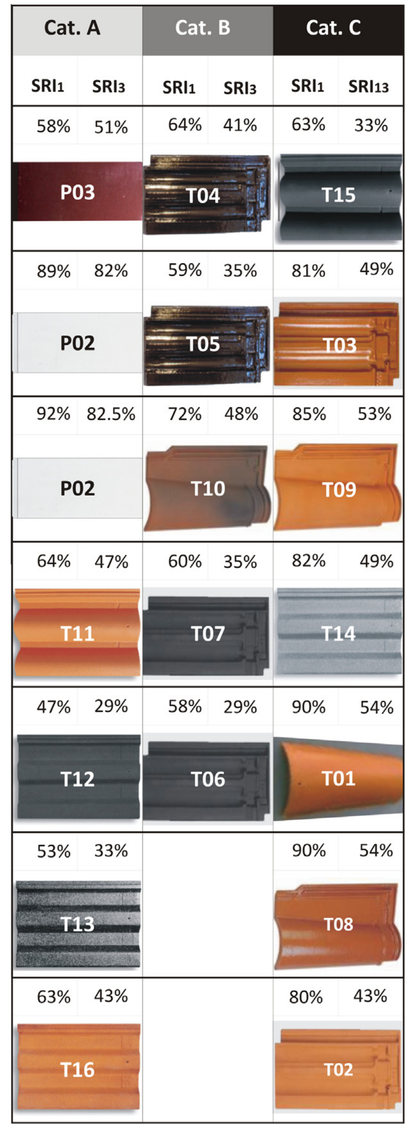


Fig. 5. Tiles (T) and roof paint (P) according to stability of his SRI values: stable (Cat. A); moderate degradation (Cat. B); severe degradation (Cat. C).

In conclusion, the characteristics of roof tiles that showed less degradation in their levels of SRI are: *acrylic* finish (100% Cat. B); *concrete* composition (67% Cat. B); the *french* shape (70% Cat. B); *black* color (86% Cat. B). Contrasting the degradation of tiles with roof paint, we observed that the behavior of all evaluated roof paint is more stable after aging because the paint has a decrease of SRI level below 20% after three years of aging.

4. Discussion

The classification of materials in line with their SRI allows for an international application of results from a regional level. This also includes a possible expansion into the energy labeling of materials. Due to the lifespan of these materials, a study of the initial thermal behavior is not enough. We must also track the evolution of SRI values throughout time. The most relevant aspects of this investigation are: (i) the description of the optical behaviors of the materials in new and aged conditions- represented by SRI value.

Table 5
Material characteristics (CHARAC.), which enhance the thermal performance of roofing materials (tiles and roof paint) during first and third years and SRI stability with aging.

Charac.	Thermal efficiency in new material		Thermal efficiency in aged material		Sri stability
Roof tiles					
Finish	**Enamel** (clay composition)	↓Ts_1 = 9 °C; ↑SRI_1 = 18%.	**Glazed** (clay composition)	↓Ts_3 = 6 °C; ΔSRI_3 = 12%.	100% Cat. C
	Acrylic (concrete composition)	↓Ts_1 = 3 °C; ↑SRI_1 = 6%.	**Acrylic** (concrete composition)	↓Ts_3 = 3 °C; ↑SRI_3 = 4%.	100% Cat. B
Comp.	Clay	↓Ts_1 = 12 °C; ΔSRI_1 = 26%.	Clay	↓Ts_3 = 3 °C; ↑SRI_3 = 7%.	50% Cat. B; 50% Cat. C
Shape	Colonial	↓Ts_1 = 5 °C; ↑SRI_1 = 10%.	Colonial	↓Ts_3 = 6 °C; ↑SRI_3 = 11%.	33% Cat. B; 67% Cat. C
Color	**Terracotta** (clay composition)	↓Ts_1 = 10 °C; ↑SRI_1 = 22%.	**Terracotta** (clay composition)	↓Ts = 13 °C; ↑SRI_3 = 25%.	37.5% Cat. B; 62.5% Cat. C
	Gray (concrete composition)	↓Ts_1 = 18 °C; ↑SRI_1 = 35%.	**Gray** (concrete composition)	↓Ts_3 = 12 °C; ↑SRI_3 = 20%.	100% Cat. C
Roof paint					
Finish	Glazed	↓Ts_1 = 1.5 °C; ↑SRI_1 = 3%.	Glazed	↓Ts_3 = 1.5 °C; ↑SRI_3 = 0.5%.	100% Cat. A
Comp.	Athermic	↓Ts_1 = 1.5 °C; ↑SRI_1 = 3%.	Athermic	↓Ts_3 = 1.5 °C; ↑SRI_3 = 0.5%.	100% Cat. A
Color	White	↓Ts_1 = 16.5 °C; ↑SRI_1 = 31%.	White	↓Ts_3 = 18 °C; ↑SRI_3 = 31%.	100% Cat. A

Cat. A: Stable; Cat. B: Moderated degradation; Cat. C: Severe degradation. ↓: decreases; ↑: increases.

These are organized according to the morphological characteristics of the materials-; and (ii) the analysis of the variation of SRI level over the passage of time, i.e. the speed with which the optical properties of a material change.

This study shows that the Solar Reflectance Index of the tiles decreases rapidly with age for all evaluated samples (75% of the tiles demonstrated SRI degradation levels higher than 20%). As a consequence, their ability for reducing urban temperatures rapidly deteriorates within the first years of their life, which eventually increases building surface temperatures from 12 °C to 24 °C. Interestingly, this trend is accentuated in materials that were initially more efficient. In contrast, 100% of roof paint is more stable after aging. Paint increases its surface temperature up to 4.5 °C after three years, and its SRI decreases up to 9%.

For example, if we compare two different roofing materials *-roof tiles versus roof paint-* of a same color *-terracotta-*: *Enamel clay roman-T08-*, initially, is the most efficient tile if compared to *Glazed waterproof -P03-* roof paint because the *-T08-* tile has an SRI_1 level of 90% and the *-P03-*paint records an SRI_1 much lower (SRI_1 = 58%). However, this is not the case after three years because the SRI_3 of paint is more stable than the tile (T08 vs. P03). The SRI levels are very similar; they both have SRI_3 between 51% and 54%.

Table 5 summarizes the characteristics of the materials that have the greatest impact on SRI values and surface temperature. The graph demonstrates the most influential materials from light to dark gray in each period as well as their degrees of stability. For example, this table shows that the initial behavior for the *colonial shape* each is more efficient because it has a surface temperature up to 5 °C cooler (Ts_1) when compared to the remaining *shapes*. Also, it has an SRI level of up to 10% higher. The same happens after three years: surface temperature differences (Ts_3) go up to 6 °C and SRI level up to 11%. By assessing the degree of stability for the *colonial shape*, one can see a severe degradation (67% of them are Cat. C) (see Table 5).

The results presented in Table 5 show that the most efficient characteristics (for both new and aged materials) are the most unstable after three years of exposure (Cat. C). Those materials with lower levels of initial SRI remain more stable after aging when these characteristics are compared.

Moreover, the Solar Reflectance Index (SRI) is affected by other aspects than those addressed in this study, such as: (i) the *position* that a material occupies in a building because some surfaces are located facing the sun -horizontally- and they are more susceptible to changes in their optical properties. A relevant future study would be to analyze the effect of slope, orientation and aging on the SRI of a given material. Also, the effect of *time* (ii) proves interesting because it was observed that all materials tend to reduce their reflectance capacity. Nevertheless, the rate at which this occurs differs according to particular morphological characteristics. It is necessary to determine whether the rate of aging is linear, which was found over the first three years, or whether the material can stabilize and maintain constant SRI levels.

The impact of *climatic conditions* (iii) of different urban environments on the optical properties of materials should be assessed according to their lifespan and compared to see if aging is faster or slower than predicted through experiments under controlled conditions to determine the cause of the behavior (sunlight/shade, rain, pollution, etc.).

Lastly, we note that other studies have evaluated the effects of aging on the SRI of roofing materials but with a focus on the influence of climatic conditions, slope, etc. [30,40]. In the literature, there is no study that considers how the morphological characteristics (finish, composition, shape and color) affect the performance of optical properties under both new and aged conditions. Addressing these issues sets this work apart.

5. Conclusions

The influence of aging on the thermal performance of roofing materials is closely related to the combined effects of their characteristics, such as finish, composition, color, and shape. *Color* is the morphological characteristic that most impacts the thermal behavior of roof coatings. Yet, 100% of the most efficient colors (gray and terracotta) are the most unstable over time (Cat. C). Therefore, this paper takes into account other morphological features and their effects on thermal performance. In the initial period, the *composition* and *finish* of the materials are crucial variables, but after three years, the most influential characteristics are *finish* and *shape*.

The results discussed in the present study indicate that the installation of tiles as roofing materials is not advisable as a strategy for urban or building heat reduction. Instead, roof paint is suggested as an effective alternative and it is easy to implement. This means that roof paint should be considered as suitable for cool roof applications and urban heat island mitigation, if applied in dense urban areas.

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References

[1] California State Enertgy Code, CEC, Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Publication P400-03-001F, California Energy Commission, Sacramento, CA, 2005–08.

[2] M. Santamouris, A. Synnefa, T. Karlessi, Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions, Sol. Energy 85 (2011) 3085–3102, http://dx.doi.org/10.1016/j.solener.2010.12.023.

[3] H. Akbari, D. Matthews, Global cooling updates: reflective roofs and pavements, in: Third International Conference Passive & Low Energy Cooling for the Built Environment (PALENC 302 2010), Rhodes Island, 29 September–1st October, 2010.
[4] H. Akbari, S. Menon, A. Rosenfeld, Global cooling: increasing world-wide urban albedos to offset CO_2, Climatic Change 94 (3-4) (2009) 275–286, http://dx.doi.org/10.1007/s10584-008-9515-9.
[5] H. Akbari, R. Levinson, A. Rosenfeld, M. Elliot, Global cooling: policies to cool the world and offset global warming from CO_2 using reflective roofs and pavements, in: Presented at the 307 Second International Conference on Countermeasures to Urban Heat Islands, Berkeley, CA 21–23 September, 2009b, doi: 10.1007/s10584-008-9515-9.
[6] H. Akbari, H. Matthews, D. Seto, The long-term effect of increasing the albedo of urban areas, Environ. Res. Lett. 7 (2012), http://dx.doi.org/10.1088/1748-9326/7/2/024004. 024004 (10pp).
[7] B. Givoni, Passive and Low Energy Cooling of Building, International Thomson Publishing Inc., NY, 1994. Wiley, pp 1–36; 81–130.
[8] G. Smitha, A. Gentlea, P. Swifta, A. Earpa, N. Mronga, Coloured paints based on coated flakes of metal as the pigment, for enhanced solar reflectance and cooler interiors: description and theory, Sol. Energy Mater. Sol. Cells 79 (2003) 163–177, http://dx.doi.org/10.1016/S0927-0248(02)00409-9.
[9] R. Levinson, P. Berdahl, H. Akbari, Solar spectral optical properties of pigments-Part I: model for deriving scattering and absorption coefficients from transmittance and reflectance measurements, Sol. Energy Mater. Sol. Cells 89 (2005) 319–349, http://dx.doi.org/10.1016/j.solmat.2004.11.012.
[10] R. Levinson, H. Akbari, J. Reilly, Cooler tile-roofed buildings with near-infrared-reflective non-white coatings, Build. Environ. 42 (2007) 2591–2605, http://dx.doi.org/10.1016/j.buildenv.2006.06.005.
[11] A. Synnefa, M. Santamouris, K. Apostolakis, On the development, optical properties and thermal performance of cool colored coatings for the urban environment, Sol. Energy 81 (2007) 488–497, http://dx.doi.org/10.1016/j.solener.2006.08.005.
[12] A. Synnefa, M. Santamouris, I. Livada, A study of the thermal performance of reflective coatings for the urban environment, Sol. Energy 80 (2006) 968–998, http://dx.doi.org/10.1016/j.solener.2005.08.005.
[13] H. Akbari, R. Levinson, Evolution of cool-roof standards in the US, Adv. Build. Energy Res. 2 (2008) 1–32, http://dx.doi.org/10.3763/aber.2008.0201.
[14] M. Santamouris, N. Papanikolaou, C. Georgakis, Square, Athens, Greece, Internal Report, Group Building Environmental Studies, Physics Department, University of Athens, Athens, Greece, 1998.
[15] D. Sailor, H. Fan, Modeling the diurnal variability of effective albedo for cities, Atmos. Environ. 36 (2002) 713–725, http://dx.doi.org/10.1016/S1352-2310(01)00452-6.
[16] P. Araújo, F. Laurenco, Measurement of albedo and analysis of influence the surface temperature of building roof materials, Energy Build. 37 (2005) 295–300, http://dx.doi.org/10.1016/j.enbuild.2004.03.009.
[17] K. Niachou, L. Livada, M. Santamouris, Experimental study of temperature and airflow distribution inside an urban street canyon during hot summer weather conditions.-Part I: air and surface temperatures, Build. Environ. 43 (2008) 1383–1392, http://dx.doi.org/10.1016/j.buildenv.2007.01.040.
[18] J. Simpson, E. McPherson, The effects of roof albedo modification on cooling loads of scale model residences in Tucson, Arizona, Energy Build. 25 (1997) 127–137, http://dx.doi.org/10.1016/S0378-7788(96)01002-X.
[19] S. Boixo, M. Diaz-Vicente, A. Colmenar, M. Castro, Potential energy savings from cool roofs in Spain and Andalusia, Energy 38 (2012) 425–438, http://dx.doi.org/10.1016/j.energy.2011.11.009.
[20] H. Akbari, R. Levinson, L. Rainer, Monitoring the energy-use effects of cool roofs on California commercial buildings, Energy Build. 37 (2005) 1007–1016, http://dx.doi.org/10.1016/j.enbuild.2004.11.013.
[21] T. Xu, J. Sathaye, H. Akbari, V. Garg, S. Tetali, Quantifying the direct benefits of cool roofs in an urban setting: reduced cooling energy use and lowered greenhouse gas emissions, Build. Environ. 48 (2012) 1–6, http://dx.doi.org/10.1016/j.buildenv.2011.08.011.
[22] M. Zinzi, S. Agnoli, Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region, Energy Build. 55 (2012) 66–76, http://dx.doi.org/10.1016/j.enbuild.2011.09.024.
[23] R. Levinson, H. Akbari, J. Reilly, Cooler tile-roofed buildings with near-infrared-reflective non-white coatings, Build. Environ. 42 (2007) 2591–2605, http://dx.doi.org/10.1016/j.buildenv.2006.06.005.
[24] R. Levinson, P. Berdahl, H. Akbari, W. Miller, I. Joedicke, J. Reilly, Y. Suzuki, M. Vondran, Solar Methods of creating solar-reflective nonwhite surfaces and their application to residential roofing materials, Energy Materials & Solar Cells 91 (2007) 304–314, http://dx.doi.org/10.1016/j.solmat.2006.06.062.
[25] R. Levinson, P. Berdahla, A. Berheb, H. Akbari, Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane, Atmos. Environ. 39 (2005) 7807–7824, http://dx.doi.org/10.1016/j.atmosenv.2005.08.037.
[26] S. Kriner, W. Miller, D. Parker, Cool Metal Roofing is Tooping the Building Envelope with Energy Efficiency and Sustainability, CEC-500-2006-067-AT11. Attachment 11: Task 2.7.1 Reports – Technology Transfer. Inc., California Energy Commission, 2006.
[27] W. Miller, K. Loye, A. Desjaralais, R. Blonski, PVDF Coatings with Special IR Reflective Pigments, CEC-500-2006-067-AT11.Attachment 11: Task 2.7.1 Reports – Technology Transfer. Inc., California Energy Commission, 2006.
[28] Environmental Protection Agency, EPA, Reducing Urban Heat Islands: Compendium of Strategies: Basic and Cool Pavements Compendium, 2008.
[29] P. Berdahl, H. Akbari, R. Levinson, J. Jacobs, F. Klink, R. Everman, Three-year weathering tests on asphalt shingles: Solar reflectance, Sol. Energy Mater. Sol. Cells 99 (2012) 277–281, http://dx.doi.org/10.1016/j.solmat.2011.12.010.
[30] P. Berdahl, H. Akbari, R. Levinson, W. Miller, Weathering of roofing materials – an overview, Construct. Build. Mater. 22 (2008) 423–433, http://dx.doi.org/10.1016/j.conbuildmat.2006.10.015.
[31] Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces, ASTM E-1980-11, 2011.
[32] J. Flores Asin, C. Martinez, M. Cantón, Tecnologías verdes. Potencial de aplicación en el área metropolitana de Mendoza (AMM). XXXVI Reunión de Trabajo de Asociación Argentina de Energías Renovables y Ambiente. Tucumán, Argentina, 2013, 22 al 25 de Octubre.
[33] N. Alchapar, Materiales de la envolvente urbana. Valoración de su aptitud para mitigar la isla de calor en ciudades de zonas áridas. Tesis Doctoral. Univ. Nacional de Salta. Facultad de Ciencia Exactas, Argentina, 2015.
[34] M. Santamouris, A. Synnefa, T. Karlessi, Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions, Sol. Energy 85 (12) (2011) 3085–3102, http://dx.doi.org/10.1016/j.solener.2010.12.023.
[35] ORNL SRI Calculator. <http://www.ornl.gov/sci/roofs+walls/calculators/sreflect/index.htm>.
[36] LBNL Heat Island Group SRI Calculator Excel Sheet. <http://coolcolors.lbl.gov/assets/docs/SRI%20Calculator/SRI-calc10.xls>.
[37] LEED's SRI Calculator. <http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1447>.
[38] H. Akbari, R. Levinson, S. Stern, Procedure for measuring the solar reflectance of flat or curved roofing assemblies, Sol. Energy 82 (7) (2008) 648–655, http://dx.doi.org/10.1016/j.solener.2008.01.001.
[39] ASTM E1918–97/06 Standard. Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field. 2006.
[40] M. Cheng, W. Miller, J. New, P. Berdahl, Understanding the long-term effects of environmental exposure on roof reflectance in California, Construct. Build. Mater. 22 (2008) 423–433, http://dx.doi.org/10.1016/j.conbuildmat.2011.06.052.