

# Energy-efficient urban buildings. Thermo-physical characteristics of traditional and recycled roofing technologies

## Sustentabilidad energética urbano-edilicia. Características termo-físicas de tecnologías de techo tradicionales y recicladas

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### Abstract

*In Latin America, the number of new materials in the construction industry has increased in the past decade. However, the information regarding their optical properties remains quite limited. The general objective of this paper is to categorize different roofing materials, according to their capacity to reduce urban temperatures by calculating the Solar Reflectance Index (SRI), in accordance with the standard ASTM E1980-11. The classification considered 31 types of roof materials of the most frequently used traditional technology in the domestic market, compared with the behavior of one tile made with rubber recycling technology. The roofing materials were classified according to morpho-material characteristics – composition, color, shape, finish. The material with the most efficient behavior is the white polyurethane liquid membrane M11 (SRI=100%) and the most inefficient is the green geotextile asphalt membrane M07 (SRI=28%), while the tile with recycled technology, black French T17, reached and SRI of 51%. Given the intrinsic characteristics of the recycled material, the tiles have great possibilities of enhancing their optothermal behavior by incorporating reflective materials in its composition.*

**Keywords:** *Optothermal properties; roofing materials; traditional technologies; recycling; morpho-material characteristics*

### Resumen

En Latinoamérica, la afluencia de nuevos materiales en la industria de la construcción ha aumentado en la última década. Sin embargo, la información de sus propiedades ópticas es muy limitada. El objetivo general de este trabajo es categorizar los distintos materiales de cubiertas de techo de acuerdo a su habilidad para disminuir las temperaturas urbanas, mediante el cálculo del Índice de Reflectancia Solar (SRI) de acuerdo a la norma ASTM E1980-11. Se clasificaron 31 tipos de materiales de techos de tecnología tradicional de mayor frecuencia de uso en el mercado nacional, en contraste con el comportamiento de 1 teja con tecnología reciclada, compuesta por residuos de caucho. Los materiales de techo fueron clasificados según características morfo-materiales -composición, color, forma, terminación-. El material que posee el comportamiento más eficiente es la membrana líquida poliuretánica blanca-M11- (SRI = 100%) y el más ineficiente es la membrana asfáltica geotextil verde -M07- (SRI = 28%). Mientras que la teja de tecnología reciclada, francesa negra-T17- alcanzó un SRI=51%. Dadas las características intrínsecas del material reciclado, las tejas presentan amplias posibilidades de mejorar su comportamiento opto-térmico mediante la incorporación de materiales reflectivos a su composición.

**Palabras clave:** Propiedades opto-térmicas; materiales de techo; tecnologías tradicionales; reciclado; características morfo-materiales

## 1. Introduction

*The cities raise the air temperature due to the modification of the natural energy balance and the increase of CO<sup>2</sup> emissions. The thermal behavior and energy performance of the cities is greatly influenced by their morphological design and material characteristics (Araújo and Laurencó, 2005) (Alchapar et al., 2017). The lowering of the surface temperature of pavements, roofs and vertical envelopes, by convective heat transfer, helps reducing the ambient temperatures. These reductions have significant impacts on cooling energy consumptions.*

*In order to achieve more sustainable cities, in environmental terms, it is essential to develop and choose construction materials with technologies that allow an energy-efficient urban model and low-carbon economy during the whole life cycle of the material. In the traditional construction, both the materials used and the production methods have a strong environmental impact, which imply the extraction of raw materials that, most of the time, are non-renewable resources.*

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According to the Argentinian National Department of Integrated Waste Management (DNGIR, in Spanish), depending from the Ministry of Environment and Sustainable Development (MAyDS), Argentina is among mid-ranked countries in terms of daily urban solid waste generation per capita; this garbage comes from residential, commercial, sanitary or industrial sectors. The average daily waste per person is 1.03 kg, which is equivalent to almost 45,000 tons per day considering the entire population (one ton every two seconds) and approximately 16.5 million each year (Devicenzi, 2018).

One alternative to reduce the environmental and energy costs associated to their manufacture is to develop materials with recycled waste composites. Within this framework, the objective of the paper is to give continuity to researches developed by the Institute of Environment, Habitat and Energy (INAHE-CONICET), evaluating the energy efficiency of different materials of urban building envelopes (Alchapar et al., 2014); (Alchapar and Correa, 2016) and delving deeper into specific developments aimed at reducing the manufacturing energy impacts, carried out by the Experimental Economical Housing Center (CEVE-CONICET). In this sense, a change in the idea of construction culture is evidenced, as well as the emergence of the so-called "new materials". The lack of awareness among users and their scarce knowledge about these materials should be highlighted as the aspects that restrict their use (Sánchez Amono, 2018).

Currently, tons of tires are temporarily eliminated in open landfills, and no effective solution has yet been found in our country. An unused tire (N.F.U., in Argentina) is that which, given its condition regarding the applicable safety standards, is not suitable for use if no techniques are applied to extend its service life. According to the information from the National Institute of Industrial Technology (INTI), it is estimated that, in our country, the annual generation of unused tires exceeds the 100,000 tons (INTI, 2015). According to the Regomax's Company, this number amounts today to 150,000 tons per year. Another abundant material is plastic, constituting 13.3% of the total urban solid waste (in weight), which is equivalent to 30% of the total (in volume) in Argentina. Among all plastics, low-density polyethylene is highlighted for its quantity, since 787,296 tons of polyethylene are generated annually (Gobierno de la Provincia de Buenos Aires, 2017); it is mainly used in the manufacture of bags, bottles, pipes, etc. This material is produced from fossil fuel and takes over 150 years to degrade outdoors. While studying the physical and mechanical characteristics of both rubber and polyethylene (LEPD), and their great availability, the decision was made to use these two types of residues, with the aim of developing a new material to be applied in a tiled roof construction technology.

A further option to promote environmental efficiency through a rational energy use, from the perspective of the material's usage, is the broad application of materials with high albedo and high thermal emittance in urban building envelopes. The international bibliography refers to these materials as cool materials (Santamouris et al., 2011); they remain cooler when exposed to solar radiation and have a greater capacity to deliver heat during the night in the form of longwave radiation, thus reducing the energy demand for cooling the buildings and improving the interior comfort of buildings without air conditioning.

Particularly, roofs are the horizontal opaque surfaces most exposed to solar radiation and, consequently, they absorb the highest thermal load of a building structure (Givoni, 1994). Several studies have described the benefits of roofs with high albedo as an effective passive strategy for cooling (Santamouris et al., 1998); (Niachou et al., 2008), quantifying the energy saved in different types of buildings and climates (Simpson, 1997); (Zinzi, 2012).

In this context, the hypothesis supported by the research indicates that, in order to achieve an energy-efficient urban building, it is necessary to make an accurate characterization of the physical properties of regional materials, according to endogenous technologies, new developments and local production. Therefore, the objective of the present work proposes a characterization of the optothermal and mechanical behavior of 32 types of roofing materials, with traditional and recycled technology, based on their capacity to reduce urban temperatures. The evaluation was made by calculating the Solar Reflectance Index (SRI), according to the standard ASTM E1980-11.

## 2. Materials and Methodology

### 2.1 Manufacturing Process

The tile manufacturing process with recycled material is made through a standard plastic extrusion machine (Figure 1), using technical specifications that optimize the tile manufacturing process carried out through a combined process of extrusion and compression molding. First, each material is separately proportioned and then they are manually mixed. The mixture of rubber and low-density polyethylene (LDPE) needed for making a tile is fed into the hopper and the paste is extruded. The machine has three heating areas (between 270 and 280°C).

The hot mix (Figure 2) coming from the extruder is fed into the lower mold of the tile. Once the amount of mix needed to fill the mold is extruded, the latter is put in the press lane in the right position, so that the upper mold is aligned, and finally, the pneumatic press is activated and the upper mold goes down, thereby applying force on



the paste. Molding is performed for five minutes, during which the paste is hardened, thus maintaining the desired shape. The recently molded tile is put onto a rack, so that it will not deform while cooling. Then, the leftover material is trimmed off.



**Figure 1.** Manufacturing process of a recycled tile. (a) General view of the extrusion machine; (b) hot mix in the mold; (c) drying rack; (d) finished sample

### 2.1.1 Physical and Mechanical Characteristics of Tiles with Recycled Composites

Following the manufacture, the tiles with recycled composites were subjected to tests, in order to determine their physical-mechanical characteristics, according to reference standards. (Table 1) indicates the results thereof, compared with tiles made with the traditional technology.

## 2.2 Solar Reflectance Index (SRI) for Roofing Materials

### 2.2.1 Sampling unit

With the aim of comparing the thermophysical behavior of different roofing materials, 32 types of roofing materials were described: 16 tiles made with the traditional technology, 1 tile with recycled composites, 7 asphalt membranes and 8 liquid membranes that are most frequently used in the domestic market (Figure 2). The applied analysis criteria categorized the roofing materials according to their composition and morphological characteristics – color, shape and finish. In order to avoid adiabatic losses, the samples were placed over a 10-cm expanded polystyrene base. The test was carried out in the property of the Regional Center for Scientific and Technological Researches (32° 53'45 " latitude south and 68° 52'28" longitude west).

**Table 1.** Physical-mechanical properties of tiles with recycled composites

<b>Tests</b>	<b>Standard</b>	<b>Laboratory</b>	<b>Results of Recycled Tiles</b>	<b>Comparison with Other Technologies</b>
Geometric Characteristics	IRAM 12528.1 Interlocking clay tiles. Part 1: Definitions and requirements.	CINTEMAC, UTN Córdoba	Dimensions: length 408.80 mm; width 230.45 mm and an average thickness of 15 mm.	Dimensions: Concrete tile: length 420.6 mm; width 331.3 mm. Clay tile: length 427.3 mm; width 224.7 mm
Mass	IRAM 12528.1 Interlocking clay tiles. Part 1: Definitions and requirements.	CINTEMAC, UTN Córdoba	1.290 kg	98% less than the zinc sheet, 74% less than the concrete tile and 52% less than the clay tile.
Specific Weight	IRAM 12528.1 Interlocking clay tiles. Part 1: Definitions and requirements.	CINTEMAC, UTN Córdoba	925 kg/m <sup>3</sup>	87% less than the zinc sheet, 57% less than the concrete tile and 43% less than the clay tile.
Water Vapor Permeance	IRAM 11632.1. Concrete tiles and accessories. Definitions and requirements.	CINTEMAC, UTN Córdoba	No water droplets in the lower part of the material.	
Air Permeability	Swiss standard SIA 262/2003. Swiss Standard: "Concrete Construction", part of Swiss structural codes	CINTEMAC, UTN Córdoba	0.0010 KT [10.16m <sup>2</sup> ] (very low)	Low
Freeze Resistance	IRAM 11632.2. Concrete tiles and accessories. Testing methods.	Structural Laboratory of the FCEF&N of the UNC	Satisfactory: No deterioration or peeling off is observed.	Satisfactory
Water Absorption	IRAM 12.528.02 Interlocking clay tiles. Part 2: Testing methods.	Structural Laboratory of the FCEF&N of the UNC	Absorbed less than 15% of its mass.	91% less than the concrete tile and 97% less than the clay tile; the zinc sheet is not water absorbent.
Shock Resistance	IRAM 12528.2. Interlocking clay tiles. Part 2: Testing methods.	Structural Laboratory of the FCEF&N of the UNC	Satisfactory: it did not break nor present surface defects.	Satisfactory





**Figure 2.** Images of evaluated roofing materials. Traditional clay and cementitious tiles (T01 to T16) and tiles with recycled composite (T17); aluminum and geotextile asphalt membranes (M01 to M07) and liquid membranes (M08 to M15)

### 2.3 Determination of Thermophysical Characteristics

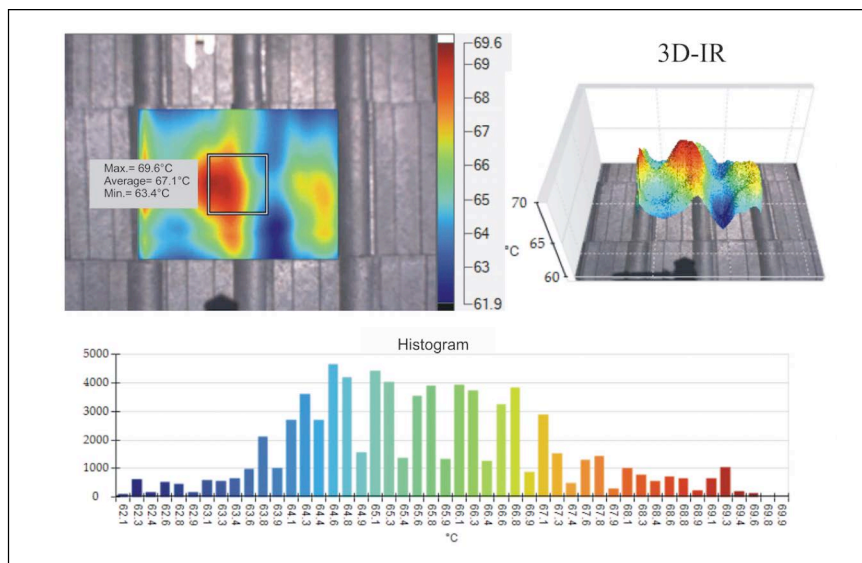
This paper quantifies the heat that a material would accumulate in relation to a white and a black reference surface, under standard ambient conditions, defined as Solar Reflectance Index (SRI), based on the standard ASTM E1980-11.

The indicator is defined by using a standard or reference black surface with an albedo of 0.05 and emittance of 0.90 equivalent to a 0% SRI; and a white reference surface with an albedo of 0.80 and emittance of 0.90, equivalent to a 100% SRI. It is expressed as a percentage between 0% and 100%. The method is applied to low-sloped opaque surfaces ( $<9.5^\circ$ ) exposed to the sun, with emissivity higher than 0.01 and surface temperatures below  $150^\circ\text{C}$ . The SRI allows a direct comparison between materials with different optical properties and it is mainly conditioned by two factors: the composition of the material and the surface texture.

The SRI is calculated with equations based on solar reflectance data or albedo ( $\hat{\alpha}$ ), emissivity ( $\epsilon$ ), and steady-state surface temperature ( $T_s$ ) previously defined and measured. An IR camera, of the type Fluke Ti 55, is used to determine the surface temperature of each material (Doulus et al., 2004) and, at the same time, the surface temperatures of each material are contrasted with type-T thermocouples incorporated to data loggers such as LASCAR EL-USB-TC, recording every minute in order to reduce possible errors during field measurements and verify the materials that might behave as selective ones (Alchapar et al., 2014); (Alchapar and Correa, 2016); (Flores and



Hongn, 2012). The solar reflectance or albedo was obtained by the alternative method of standard ASTM E1918-06: Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-sloped Surfaces in the Field, developed by (Akbari et al., 2008), using an albedometer of the type Kipp & Zonen CMA11 (spectral range of 285 to 2800  $\mu\text{m}$ ). The thermal emissivity was obtained by the method ASTM E1993-14: Standard Practice for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometer. A Fluke 568 IR thermometer with emissivity adjustment was used for its evaluation, together with a T thermocouple incorporated to data loggers, such as LASCAR EL-USB-TC. (Figure 3) shows the surface temperature distribution of the tile with recycled composites (T17), recorded with a Fluke Ti55 IR camera, under standard ambient conditions according to ASTM E1980-11.



**Figure 3.** Infrared image of the tile with recycled composites (T17). Plan view, axonometric view and distribution of surface temperature frequencies

### 3. Results

Following the tests under controlled conditions, (Table 2) describes the optothermal properties obtained according to the morphological characteristics and the composition of each material. The results are indicated according to the following classification criteria:

SRI levels greater than or equal to 75% are considered efficient materials; SRI levels between 74% and 50% mean moderate efficiency; and SRI levels between 49% and 25% are inefficient materials for reducing surface and urban temperatures.

#### 3.1 SRI of extreme cases

- **Most efficient material:** When contrasting the behaviors recorded in the total samples, it is possible to observe that the material with the most efficient behavior is the white matte polyurethane liquid membrane M10, which registered SRI levels = 100%, albedo = 0.78 and thermal emissivity = 0.95 (Table 2).

- **Inefficient material:** The roofing material that elevates its surface temperature the most, and therefore has a lower SRI level, is the green matte geotextile asphalt membrane M07, with a SRI = 28%, albedo = 0.40 and thermal emissivity = 0.98. When particularly analyzing the tile element, this coating typology evidenced an intermediate behavior, in relation to the membranes, with SRI levels ranging between 90% and 47% (Table 2).

#### 3.2 SRI according to the Materials Morphological Characteristics

In the following analysis, in order to evaluate the SRI dependence degree with regard to a variable (composition, shape, finish and color), the remaining variables are kept constant in each roof typology. (Figure 2) shows the frequency distributions of SRI levels, according to the morphological characteristics of membranes and tiles.



**Table 2.** Characterization of optothermal and morphological properties and the composition of each type of roofing material evaluated: tile (T) and membrane (M)

CODE	COMPOSITION	MORPHOLOGICAL CHARACTERISTICS			OPTOTHERMAL PROPERTIES				
		Shape	Finish	Color	â	a	e	T <sub>s</sub>	SRI
<b>T01</b>	Clay	Spanish Colonial	Natural	Terracotta	0.71	0.29	0.90	43.00	90
<b>T02</b>	Clay	French	Natural	Terracotta	0.62	0.38	0.90	48.00	80
<b>T03</b>	Clay	French	Enamel	Terracotta	0.64	0.36	0.90	47.00	81
<b>T04</b>	Clay	French	Bifired enamel	Black	0.47	0.53	0.95	56.00	64
<b>T05</b>	Clay	French	Monofired enamel	Black	0.41	0.59	0.98	58.00	59
<b>T06</b>	Clay	French	Bifired matte	Black	0.41	0.59	0.98	58.00	58
<b>T07</b>	Clay	French	Monofired matte	Black	0.43	0.57	0.95	57.00	60
<b>T08</b>	Clay	Roman	Enamel	Terracotta	0.71	0.29	0.95	42.00	90
<b>T09</b>	Clay	Roman	Natural	Terracotta	0.67	0.33	0.90	45.00	85
<b>T10</b>	Clay	Roman	Aged	Terracotta	0.55	0.45	0.95	51.00	72
<b>T11</b>	Cementitious	Spanish Colonial	Natural	Terracotta	0.47	0.53	0.95	55.00	64
<b>T12</b>	Cementitious	French	Matte	Black	0.31	0.69	0.95	64.00	47
<b>T13</b>	Cementitious	French	Acrylic enamel	Black	0.37	0.63	0.95	61.00	53
<b>T14</b>	Cementitious	French	Natural	Gray	0.65	0.35	0.90	46.00	82
<b>T15</b>	Cementitious	Spanish Colonial	Matte	Black	0.46	0.54	0.95	56.00	63
<b>T16</b>	Cementitious	French	Matte	Terracotta	0.46	0.54	0.95	56.00	63
<b>T17</b>	Recycled Composites	French	Matte	Black	0.32	0.68	0.86	67.00	51
<b>M1</b>	Aluminum asphalt	n/a	Gloss	Uncoated	0.84	0.16	0,05*	54.50	69
<b>M2</b>	Aluminum asphalt	n/a	Matte	White	0.71	0.29	0.90	45.50	85
<b>M3</b>	Aluminum asphalt	n/a	Matte	Red	0.43	0.57	0.98	75.00	32
<b>M4</b>	Aluminum asphalt	n/a	Matte	Green	0.39	0.61	0.98	77.00	29
<b>M5</b>	Geotextile asphalt	n/a	Matte	White	0.70	0.30	0.90	48.00	81
<b>M6</b>	Geotextile asphalt	n/a	Matte	Red	0.44	0.56	0.98	76.00	30
<b>M7</b>	Geotextile asphalt	n/a	Matte	Green	0.40	0.60	0.98	77.50	28
<b>M8</b>	Eco liquid 4000	n/a	Matte	White	0.69	0.31	0.85	44.00	87
<b>M9</b>	Premium liquid	n/a	Matte	White	0.66	0.34	0.94	45.00	86
<b>M10</b>	Polyurethane liquid 4000	n/a	Matte	White	0.78	0.22	0.95	36.50	100
<b>M11</b>	Eco liquid	n/a	Matte	White	0.65	0.35	0.95	45.50	85
<b>M12</b>	Acrylic liquid	n/a	Matte	White	0.79	0.21	0.95	36	100
<b>M13</b>	Polyurethane liquid 5000	n/a	Matte	White	0.72	0.28	0.95	41.00	94
<b>M14</b>	Fiber liquid	n/a	Satin	White	0.83	0.17	0.90	43.00	89
<b>M15</b>	Fiber liquid	n/a	Satin	Red	0.61	0.39	0.95	59.50	58

n/a: does not apply; (\*) reference data



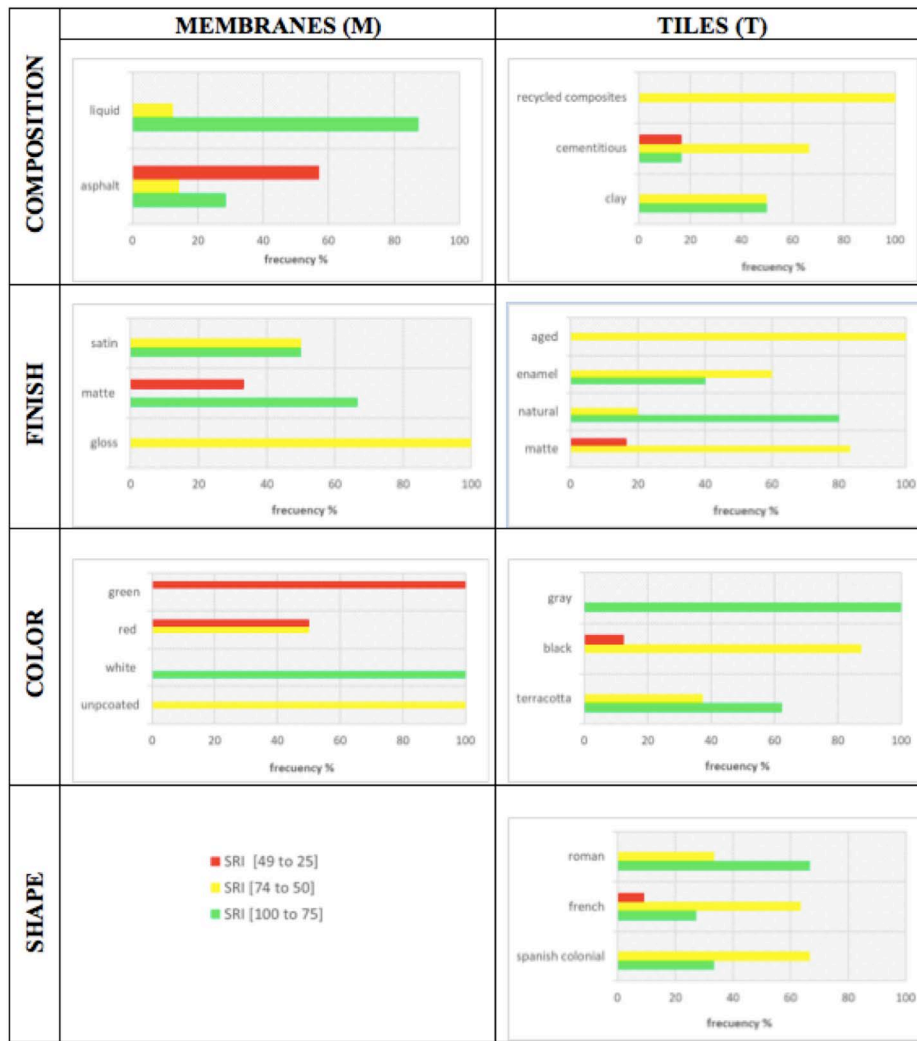


Figure 4. Diagram of the frequencies of SRI levels, according to the morphological characteristics (composition, finish, color and shape) of membranes and tiles

### 3.3 SRI according to the Composition

- **Membranes - asphalt versus liquid:** the composition that registers the highest efficiency for reducing urban temperatures is the liquid one. 87.5% of the membranes evaluated with this composition registered SRI levels over 75% and the remaining 12.5% showed a moderate performance. The asphalt composition has more extreme behaviors, where 57% showed low SRI levels and 28.6% were more efficient. Specifically, the aluminum asphalt membranes were cooler than the geotextile asphalt membranes see M2, 3, and 4 versus M5, 6, and 7 in (Table 2) and (Figure 4).

- **Tiles – clay versus cementitious and with recycled composites:** the clay composition showed the best performance in terms of surface temperature and SRI, when color, finish and shape are kept constant. From the total evaluated tiles, 50% showed SRI levels over 75% and the remaining 50% reached a moderate efficiency. 83.3% of the tiles with cementitious composition has a moderate efficiency, except the black T12 tile, which showed the most efficient behavior, with levels of SRI = 47%. It is important to highlight that clear colors significantly improve the thermal behavior of cementitious tiles see T12 versus T14 in (Table 2). With regard to the tile composition with recycled materials, the tested sample showed a moderate efficiency, with a SRI = 51%. This is because the tested tile was black and, therefore, had low levels of albedo = 0.32, in addition to its relatively low thermal emissivity see T17 in (Table 2) and (Figure 4).





### 3.4 SRI according to the Finish

- **Membranes – matte versus satin and gloss:** 67% of the membranes with matte finish and 50% of the membranes with satin finish have high levels of albedo, while the gloss finish has a moderate efficiency. It should be noted that, of all the tested samples, the only two materials with SRI = 100% had a matte finish see M10 and M12 in (Table 2) and (Figure 4).

- **Tiles – matte versus natural, enamel and aged:** In contrast with the membranes, the most efficient finish for tiles is natural and enamel, with a frequency of 80 and 40%, respectively. Darker tiles significantly improve their performance with the enamel finish; differences in the levels of SRI = 11.5% were recorded see T4 versus T12 in (Table 2). The matte and aged finishes showed a moderate or inefficient behavior, with SRI below 50%.

### 3.5 SRI according to the Color

- **Membranes – white versus terracotta, red, green and uncoated:** In general, in all compositions and finishes, white colors showed a greater capacity, with an average SRI of 90%. The uncoated membrane came second, with a SRI of 68%, followed by the red color in the third place. Specifically, the red color membrane M15 obtained a good performance with an SRI of 58%. Instead, the green color always presented low reflectivity levels (SRI below 29%). In other words, the colors registered differences of SRI  $\geq$  71% see M4 and 7 versus M2, 5, 8, 9, 10, 11, 12, 13, and 14 in (Table 2) and (Figure 4).

- **Tiles – terracotta versus black and gray:** the vast majority of the tiles registered a good behavior, with SRI  $\leq$  50. The terracotta colors obtained the lowest surface temperatures, with an average SRI = 78%. However, the black color showed efficient performances in the clay compositions and with recycled composites. Black tiles showed average SRI levels of 60% in the clay composition and 51% with recycled composites see T4, 5, 6, 7 and T17 in (Table 2) and (Figure 4).

### 3.6 SRI according to the Shape

- **Tiles – French, Roman and Spanish colonial:** according to the classification by shape, Roman tiles with different compositions, colors and finishes reached average SRI levels of 82%. The second most efficient was the Spanish colonial shape; the remaining 33% of the tested samples registered SRI level over 75%. Particularly in the black tiles, the French shape showed the best performance in terms of surface temperature and SRI = 63.5% see T04 in (Table 2) and (Figure 4).

## 4. Conclusions

The emergence of new materials in the construction industry has increased in the last decade at regional level. However, the information concerning their optical properties is very limited and, at the same time, the characterization of recently developed construction materials is neither common knowledge. In order to improve both the energy efficiency of the materials and the exploitation and rational use of energy by properly choosing them, it is essential to generate and disseminate this knowledge among all stakeholders – industry, commercial sector, users, government, and scientific field.

This paper allowed creating a database of thermal and physical properties of materials used in traditional and recycled roofing technologies, according to their morphological characteristics. This knowledge improves the prediction and precision analysis of the energy behavior of materials at urban building scale.

The comparison of the physical-mechanical behavior between tiles with recycled composites and traditional roofing materials produced the following results:

- In relation to the technical aspects, the main advantages of the tiles with recycled composites is their lower density and water absorption, greater shock resistance in case of hard impacts (hail) and greater flexural strength.

- Considering the environmental aspects, the main advantages is that they contribute to the pollution control, since they are entirely constituted by recycled waste materials, instead of using non-renewable raw materials.

The comparative optothermal analysis for each material determined the following:

- Among the most efficient morphological characteristics in membranes, the liquid composition, the white color and the matte finish were the most efficient variables. The liquid membranes M10 and M15 produced the maximum SRI levels (100%).



- With regard to the tile technology, the Roman composition, the terracotta color, the natural or enamel finish and the Roman shape were the characteristics with the most efficient behavior in reducing the surface temperatures of the roofs. The tiles with the highest SRI levels (90%) were the clay tiles T01 and T08.

When specifically evaluating the tile with recycled composites, it showed a moderate efficiency, with levels of SRI = 51%. It should be highlighted that the evaluation was made only on a black tile, which a priori presents lower albedo levels. However, given the intrinsic characteristics of the recycled material, the tiles show great possibilities of enhancing their optothermal behavior by incorporating reflective materials in their composition, in the form of micro spheres or addition of titanium dioxide powder (TiO<sub>2</sub>), and also by making efforts to increase the emissivity levels. Future papers plan to evaluate tile typologies with recycled composites in different colors, shapes and textures.

## 5. Acknowledgements

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