Albedo Quantification Using Remote Sensing Techniques. Cool Roof in the Metropolitan Area of Mendoza- Argentina

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Abstract. The presence of cities raises air temperature. The growth of sealed urban surfaces and anthropogenic heat modifies the natural energy balance increasing the CO2 emissions of a city. A strategy to reduce urban temperatures and energy consumption is the widespread application of cool materials -with high albedo and high emissivity- in the urban envelope. Roofs are the horizontal opaque surfaces most exposed to solar radiation and are therefore the ones that absorb the highest thermal load of a building. The objective of this research is to design a procedure that allows the discrimination the different roofing materials within the Metropolitan Area of Mendoza, Argentina, to determine the possible energy savings and improvements in urban microclimatic conditions associated with the increase of albedo in the roofs of the city. The methodology is based on a supervised classification of roof materials using spectral signatures with QGIS 3.2 ‘Bonn’ software. For this purpose, images from the Sentinel 2a platform were used and 3 series of spectral signatures were obtained from built urban areas. The results show that the materials mainly used in the roofs of the city of Mendoza are membranes (74%), zinc sheet (14%) and traditional tiles (13%). These findings represent an efficient tool to quantify the energy and environmental effects of regulating albedo values in urban roof.

1. Introduction
The Mendoza’s metropolitan area (AMM) is a city with an arid climate, located in the center west of Argentina. Although it has urban canals with intensive forestation, the city's heat island reaches values of 10°C, both in the summer and winter periods. This phenomenon increases energy consumption in summer by approximately 20%, due to the cooling needs to achieve indoor comfort conditions. Studies over the past decade have concluded that the main causes are determined by erroneous combinations between urban design, local climatic characteristics and the geographical location of the city [1]. To mitigate the negative effect of city growth on microclimate, various urban cooling strategies have been studied, among the most relevant, research has shown that the application of cool materials offers large possibilities to lower urban temperature. Alchapar et al., 2017 [2] indicated that every increase of 10% in the level of albedo of roofs and pavements in the city of Mendoza-Argentina, produces a decrease in the outdoor air temperature of 0.75°C.
Materials that record high levels of albedo and thermal emissivity are internationally defined as cool roofs [3]. These properties allow for greater reflection of solar radiation and greater emission of the heat from buildings into the atmosphere, thus reducing the use of energy to cool buildings. Considering that roofs cover about 20-25% of a city's surface, extensive application of cool materials could mitigate the heat island effect and reduce urban temperatures associated with global climate change [4, 5, 6, and 7].

To assess the energy savings associated with this strategy, it is necessary to quantify the albedo of roofs throughout the city. The international academy has documented numerous difficulties associated with the quantification of albedo on urban-scale roofs such as: spatial coverage, spatial resolution, spectral coverage, radiometric calibration and cost. Albedo characterization methodologies can be classified according to accuracy and area of intervention. For example, the use of a spectrophotometer, usually equipped with an integrative sphere attachment for hemispheric reflectance measurements, allows the analysis of various materials across the spectrum range, according to ASTM, 2010 [8]. This methodology, characterized by a high level of detail, involves the collection of samples and their transport to the laboratory, making any large-scale application unfeasible. The difficulty of transferring samples from the field to the laboratory for analysis could be overcome with field instruments such as alscalemeters, which consist of two pyranometers that detect total descending and ascending flows, both in short-wave and long-wave spectrals regions, according to methodology described in ASTM, 2016 [9]. Although this method is more affordable, its application is maintained at a local scale and its extension to entire cities is not feasible at reasonable costs [10]. Within this framework, satellite measurements show the potential to overcome all the difficulties listed above, as they provide global spatial coverage, making it possible to monitor albedo changes over time, thanks to frequent satellite passages on the same sector of the earth [11].

The albedo of urban areas obtained through satellite observations has been carried out mainly in countries of North America, Europe, Asia and Africa, whereas in Latin America, studies are currently incipient. For example, Konopacki and Akbari, 2004 [12] focused on the study of surface solar reflectance in U.S. cities, and Ban-Weiss, et al., 2015a, b [10, 13] have worked intensively on the quantification of albedos on roofs in 7 cities of California. Haixia et al., 2012 [11] recorded the variation of albedo on the Earth's surface in Beijing; while in Europe, Stathopoulou et al., 2009 [14] analyzed the metropolitan area of Athens. Boixo et al., 2012 [15] concentrated their study on possible energy savings in cities in Spain, and Baldinelli et al., 2015 [16] compared the veracity of the solar reflectance data of the roofs through Landsat Thematic Mapper versus infrared thermography in the air, considering how the different sun exposures of the same surface affect their results in Italian cities. Greater London Authority and London Climate Change Partnership, 2015 [17] have identified urban albedo as one of the most important parameters for mitigating the urban heat island in London. This program is currently carrying out a project called 'Urban Albedo Computation in High Latitude Locations: An Experimental Approach funded by the Research Council of Engineering and Physical Sciences (EPSRC).

Research carried out in Mendoza, Argentina by Alchapar y Correa, 2016 [18] evaluated various local materials used in the urban envelope. Specifically, they optically and thermally characterized different types of pedestrian pavements and membranes, under conditions of new and aged material.

In this context, identifying roofing materials on an urban scale and determining their covered surface is key to estimate the energy-saving potential of implementing cool roofs. Therefore, the objective of this research is to obtain a procedure that allows to discriminate the different materials of the roof surfaces of Mendoza, Argentina to determine the reduction in surface temperature caused by the increase in albedo level on the roofs of the city. From this knowledge it will be possible to determine specific policies and assess the impact of possible interventions at the local level. Another section of your paper.

2. Study area

The research was carried out in the Mendoza’s metropolitan area (AMM), Argentina (32o54'48" S, 68o50'46" W). AMM has an open urban geometry, composed of wide and highly shaped road channels. It is a complex urban area composed of different types of roofing materials, pavements and urban
vegetation. The city occupies an area of 168 km², the 22% (36.71 Km²) is covered by buildings and 78% (131.29 Km²) of the surface is covered by vegetation, land and asphalt.

2.1. Local context: Distribution of roof materials in Mendoza-Argentina.
In 2010, a total of 494,841 houses were surveyed in the province of Mendoza on the item “Advances in Civil Engineering of Population, Homes and Houses” as part of the National Census of Argentina. This research highlighted that the roofs are built with materials such as: asphalt or membrane (265817 homes); (72329 homes); tile or slab (63655 homes); slates or roof tiles (43472 homes); fibrocement or plastic sheets (4873 households); cardboard (891 households); and others (35645 households). That means that 79% of the houses have membranes, sheet metal or shingles on their roof (Table 1).

Table 1. Homes of the province of Mendoza, Argentina according to the predominant material of the outer roof and presence of ceiling. (National Census, in the Province of Mendoza, 2010).

| Total households | 494,841 |
|------------------|---------|
| Asphalt cover or membrane with ceiling | 176,843 |
| Asphalt cover or membrane without a ceiling | 88,974 |
| Flooring tile or slab with a ceiling | 45,449 |
| Flooring tile or slab without a ceiling | 18,206 |
| Slate or roofing tile with a ceiling | 31,632 |
| Slate or roofing tile without a ceiling | 11,840 |
| Zinc sheet with ceiling | 55,046 |
| Zinc sheet without ceiling | 17,283 |
| Fibrocement or plastic sheet with ceiling | 2,598 |
| Fibrocement or plastic sheet without a ceiling | 2,275 |
| Cardboard with ceiling | 251 |
| Cardboard without ceiling | 640 |
| Cane, board or straw with clay, single straw with ceiling | 8,101 |
| Cane, board or straw with clay, single straw without ceiling | 27,544 |
| Others with a ceiling | 2,145 |
| Others without a ceiling | 6,014 |

3. Methodology
To achieve the stated objective, this research was conducted at two analysis scales:
- At urban level: satellite techniques determined the distribution percentage of the covered area of each type of roofing material.
- At the object level: a sample of higher diffusion roof materials was evaluated in the province through tests under controlled conditions, with the aim of determining the initial albedo (or solar reflectance) and its response to aging.

3.1. Assessment of roofing materials by satellite image

3.1.1. Supervised classification
In supervised classification, representative samples must be selected for each soil coverage class. The software uses these "training areas" and applies them to the entire image, that is, with the pixel attributes of a known identity, pixels of unknown identity are classified [19]. Supervised classification uses the spectral signature defined in the training set. For example, it determines each class considering the main similarities with the training areas (called ROIs- Regions of interest). Common supervised classification
algorithms are the maximum probability and the minimum distance classification. In this work, a supervised classification of the predominant roofing materials was carried out with the aim of obtaining a procedure that allows to discriminate the different roof materials used in the AMM.

3.1.2. Satellite imagery datasets

Satellite imagery was acquired from the Sentinel 2A platform, downloaded from Earth Explorer from the USGS, which has extensive territorial and temporal coverage in the area, ensuring the possibility of replication. To reduce possible uncertainties due to the projection of shadows from the canopy of the trees on the roofs, the analyzed images correspond to July 30, 2018 (winter in the southern hemisphere) at 02:43:13 UTC. The free QGis 3.2 'Bonn' software was used in the processing and analysis of satellite images. Calibration and atmospheric correction of all bands was performed automatically using the DOS1 method and digital levels were converted to reflectance values [20]. Upon completion of this stage, a band overlay was generated, resulting in a virtual raster.

3.1.3. Removing pixels from the roofing of the images

The pixels were extracted from the roof using a vector file of roofs of the AMM (Source: General Direction of Cadastral) as a previously processed image cutting layers (mask layer) and eliminating free spaces and roads. The "Semi-Automatic Classification Plugin" (SCP) applied the Supervised Classification to the Deck Clipper. The classes were defined as: membrane (yellow), roofing tile (red) and zinc sheet (cyan), which are the predominant roofing materials in the study area. ROIs training was selected for each material based on the knowledge and certainty that the selected roofs correspond to the predefined categories (membrane, roofing tile or zinc sheet). In this phase, the spectral signature database is created, which the software uses to identify unknown pixels. The result of the process is a raster, where each pixel has been assigned the color of that category, and unclassified areas are assigned black. Finally, the Grass Gis "r.report" algorithm of the raster toolbox was used to calculate the area of each class.

3.2. Characterization of albedos of roofing materials under controlled conditions

Surface or albedo solar reflectance is physically defined as the ratio between the power of the reflected radiation and the total power received by it. Since the amount of radiation reflected by the surface will always be less than or equal to the received power, the reflectance will have values between 0 and 1. Research by Lawrence Berkeley National Laboratory, Oak Ridge Laboratory and EPA has shown that the initial high albedo of a roof can be degraded by soot, dust and sun exposure.

To determine the initial and aging optical behavior of roofing materials available on the local market, 16 roofing tiles and 8 asphalt membranes were evaluated under different characteristics including shape, color and termination. The optical behaviors of the materials were studied during three summer periods, 2017, 2018 and 2019, at the Regional Center for Scientific and Technical Research located to the west of the city (32°53 S and 68° 51 W).

3.2.1. Material and method

The methodology used to evaluate the value of albedo under new and aged conditions is based on research carried out by Alchapar & Correa 2015. The albedo (â) of each sample was monitored following the method developed by Akbari et al., 2008 [21].

4. Results

4.1. Spectral signatures of roofing materials

Based on the results presented in Table 1, which states that 79% of Mendoza's roofs are built with membranes, tiles or zinc sheets, 10 ROIs were selected for each of the three materials.

Figure 1 represents the mean, maximum, and minimum composition of spectral signatures for each material type. Characterized spectral signatures have a spectral range of 443 to 2190 nm. The statistics
show that the reflectance of roofing materials ranges from 0.05 to 0.37 depending on the wavelength. These variations in albedo levels are the result of the different responses of the materials evaluated under aging conditions to which they are exposed in the study area. The material with the highest integrated solar reflectance is the zinc sheet, with a maximum reflectance of 0.27.

![Membrane](image1)

![Roofing Tile](image2)

![Zinc sheet](image3)

**Figure 1.** Average spectral signature graph according to roofing material.

4.2. *Albedo assessments under controlled conditions*

Figure 2 shows the distribution percentage of albedo of membranes and roofing tiles evaluated in the laboratory, under new material conditions and at 3 years of aging. The graphs show that 42% of new membranes have an albedo level of more than 0.7, while 38% of new tiles reach these levels. During
aging, 100% of membranes record albedos greater than 0.50, while only 19% of aged tiles reach these levels.

This study shows that the albedo of all the evaluated roofing tiles decreases rapidly with the exposure to the weather (75% of the tiles showed albedo degradation levels above 20%). This trend is accentuated in materials that were initially more efficient, in contrast to 100% of the membranes that proved more stable after aging. This is equivalent to data obtained by the Cool Roof Rating Council (CRRC), which is the organization that develops and implements energy performance rating systems for highly reflective roof surfaces.

4.3. Mapping roofing materials in the AMM

According to the spectral signatures generated by the method proposed in the GIS, Figure 3 maps the roofing areas according to the type of material in the Mendoza Metropolitan Area. Over a total area of 36.71 km² the distribution percentage of the different types of roofing materials is: 74% membranes, 14% zinc sheets and 13% roofing tiles. These results reveal the high rehabilitation potential of the roofs of the city of Mendoza, with records of 88% occupancy, membranes and zinc sheets offer great possibilities for the application of reflective paints, which allow to raise the albedo levels of their surfaces.
Figure 3. Distribution of roofing materials in Mendoza’s metropolitan area (AMM)

5. Conclusions
The results achieved in this research showed that satellite observations with adequate spatial resolution can be successfully applied to quantify the materials of deck surfaces with a good level of approximation, precisely defining reflective properties in simple roofing or individual areas.
In the study area the distribution of roofing materials resulting from the supervised classification consists of 74% membranes, 14% sheet metal and 13% shingles. As a result, the city of Mendoza shows great possibilities to increase albedo levels on low slope ceilings by applying high-performance reflective paints.

According to laboratory tests, monitoring indicated that more than 38% of roofing materials under new material conditions register an albedo greater than 0.7, while all the evaluated membranes present stability greater than roofing tiles after 3 years of aging.

The solar reflectance values obtained in the laboratory for 3 years are not comparable to the albedo ranges of the roofs with the longest exposure periods in the city. Due to the extreme climatic factors presented in the city of Mendoza, flat roof coverings tend to dry out and break due to intense solar radiation, dirt and hail.

The quantification and mapping of roofing materials according to their solar reflectance is a decisive tool for estimating the energy-saving potential derived from the appropriate selection of materials for urban rehabilitation or new projects in Mendoza, Argentina.

In future work, the long term effects of this cooling strategy will be evaluated considering the costs associated with replacing or rehabilitating roofing materials in relation to the energy savings it could drive.

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References
[1] Correa E 2006. Isla de calor urbana. El caso del área metropolitana de Mendoza”. Tesis doctoral. Universidad Nacional de Salta, Facultad de Ciencias Exactas, Salta, Argentina
[2] Alchapar N, Pezzuto C, Correa E y Labaki L 2017. The impact of different cooling strategies on urban air temperatures: the cases of Campinas, Brazil and Mendoza, Argentina. Theoretical and Applied Climatology 130(1-2), pp. 35-50. https://doi.org/10.1007/s00704-016-1851-5
[3] Santamouris M, Synnefa A y Karlessi T 2011. Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Solar Energy 85 (12), pp. 3085-3102. http://dx.doi.org/10.1016/j.solener.2010.12.023
[4] Taha H, Akbari H, Rosenfeld A y Huang J 1988. Residential cooling loads and the urban heat island-the effects of albedo. Build. Environ. 23, pp. 271-283.
[5] Akbari H, Rosenfeld A y Taha H 1990. Summer heat islands, urban trees, and white surfaces. In: Proceedings of the 1990 ASHRAE Winter Conference.
[6] Rosenfeld A, Akbari H, Bretz S, Fishman B, Kurn D, Sailor D y Taha H 1995. Mitigation of urban heat islands: materials, utility programs, updates. Energy Build. 22: 255-265. https://doi.org/10.1016/0378-7788(95)000927-P
[7] Vahmani P, Sun F, Hall A y Ban-Weiss B 2016. Investigating the climate impacts of urbanization and potential for cool roofs to counter future climate change in Southern California. Environmental Research Letters 11:124027. https://doi.org/10.1088/1748-9326/11/12/12402
[8] Prado R, y Ferreira F 2005. Measurement of albedo and analysis of its influence the surface temperature of building roof materials. Energy Build. 37(4):295-300. https://doi.org/10.1016/j.enbuild.2004.03.009
[9] Alchapar N, Correa E y Canton M 2014. Classification of building materials used in the urban envelopes according to their capacity for mitigation of the urban heat island in semiarid zones. Energy and Buildings 69:22-32. https://doi.org/10.1016/j.enbuild.2013.10.012.
[10] Ban-Weiss G, Woods J, y Levinson R 2015a. Using remote sensing to quantify albedo of roofs in California’s seven largest cities, Part 1: Methods. Solar Energy 115: 777-90. https://doi.org/10.1016/j.solener.2014.10.022
[11] Haixia F, Heng D, Chao C, Qingye M, y Guoqiang A 2012. The variation analysis of land surface
albedo in Beijing in recent ten years. In: Geoscience and Remote Sensing Symposium (IGARSS), Munich, Germany, pp. 6309-12.

[12] Konopacki S, y Akbari H 2001. Measured energy savings and demand reduction from a reflective roof membrane on a large retail store in Austin. Lawrence Berkeley National Laboratory Report LBNL-47149, Berkeley, CA. https://doi.org/10.1016/S0924-2716(03)00016-9

[13] Ban-Weiss G, Woods J, Millstein D y Levinson R 2015b. Using remote sensing to quantify albedo of roofs in California’s seven largest cities, Part 2: Results and application to climate modeling. Sol. Energy 115:791-805. https://doi.org/10.1016/j.solener.2014.10.041

[14] Doussset B y Gourmelon F 2003. Satellite multi-sensor data analysis of urban surface temperatures and landcover. ISPRS J. Photogramm. Remote Sens. 58 (1-2): 43-54. https://doi.org/10.1016/S0924-2716(03)00016-9

[15] Stathopoulou M y Cartalis C 2009. Downscaling AVHRR land surface temperatures for improved surface urban heat island intensity estimation. Remote Sens. Environ. 113 (12): 2592-2605. https://doi.org/10.1016/j.rse.2009.07.017

[16] Boixo S, Diaz-Vicente M, Colmenar A, Alonso Castro M 2012. Potential energy savings from cool roofs in Spain and Andalusia. Energy 38(1):425-438. https://doi.org/10.1016/j.energy.2011.11.009

[17] Baldinelli G, Bonafoni S, Anniballe R, Presciutti A, Gioli B y Magliulo V 2015. Spaceborne detection of roof and impervious surface albedo: Potentialities and comparison with airborne thermography measurements. Solar Energy 113: 281-294, https://doi.org/10.1016/j.solener.2015.01.011.

[18] London Plan March 2015. Further Alterations to the London Plan (FLAP). Chapter nº 5 London's Response to Climate Change. Greater London Authority ed.

[19] Alchapar N, Correa E. 2016. Aging of roof coatings. Solar reflectance stability according to their morphological characteristics. Construction and Building Materials 102 (1): 297-305. https://doi.org/10.1016/j.conbuildmat.2015.11.005.

[20] Instituto Nacional de Estadísticas y Censos-INDEC, Censo de Población del año 2010. Tipos de Cubierta Empleados en la Provincia de Mendoza, Argentina, 2010. https://www.indec.gob.ar/censos_provinciales.asp?id_tema_1=2&id_tema_2=41&id_tema_3=135&p=50&d=999&t=0&s=0&c=2010.

[21] Linares S y Tisnés A 2011. Extracción y análisis de superficies urbanas construidas empleando imágenes LANDSAT 5 (TM). Congreso Nacional de Geografía de Universidades Nacionales, At Resistencia, Chaco, Argentina.

[22] Picone N 2017. Comparación de imágenes satelitales Sentinel 2 y Landsat 8 en el estudio de áreas urbanas. Congreso Nacional de Geografía de Universidades Nacionales, At Resistencia, Chaco, Argentina.

[23] Akbari H, Levinson R y Stern S 2008. Procedure for measuring the solar reflectance of flat or curved roofing assemblies. Solar Energy 82 (7):648-655, https://doi.org/10.1016/j.solener.2008.01.001.