URBAN HEAT ISLAND MITIGATION. CLASSIFICATION OF BUILDING MATERIALS USED IN THE URBAN ENVELOPES ACCORDING THEIR CAPACITY FOR COOLING THE CITY.

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1. Introduction

Increase of urban temperature has a direct effect on energy consumption, thermal comfort and environmental contamination of cities. High urban temperatures condition both: energy consumption for thermal conditioning in buildings during summer and habitability (degree of comfort) of open areas in the city (streets, sidewalks, squares, etc.) (Akbari et al, 1992).

Internationally, the different strategies formulated to mitigate the urban heat island are sustained in two principles: Increase the green coverage of the areas and work on the thermophysical properties -albedo, emissivity, rugosity, etc- of the materials used in the resolution of the surroundings (roofs, pavements and facades) of urban areas.

The use of "cold materials", related to the increase of green spaces is a low cost and viable alternative, which may be implemented in urban areas and in constructing new buildings, as a new strategy for reducing damaging effects of the heat islands (Araújo, Laurenco, 2005), in particular in areas with water shortage as in the case of Mendoza, Argentina.

The first step for the practical application of these concepts is characterizing thermo-physical and optical properties of the materials of urban enveloping surface.
The albedo directly affects in the urban energetic balance when determining the fraction of absorbed incident sun energy. Sun reflectance and thermal emittance are important factors affecting the surface temperature of the material and the air near surface. Surfaces with low sun reflectance absorb a higher amount of incident sun energy. A fraction of this energy is conducted into the soil and the buildings, a fraction is transmitted by convection into the air (leading to an increase of air temperature) and a fraction is irradiated to sky.

The study is developed in Mendoza, Argentina, a urban conglomerate near one million people, located in an arid and seismic context, which presents an open urban geometry, formed by heavy tree-covered wide streets and a pyramidal-type civic structure. In this place, the maximum civic concentration and verticality are found in the city center, diluting to the periphery, where the suburbs are located, forming a low-density environment. The Mendocinian urban-civic surrounding areas is made up by a range of different materials. These are the result of applying traditional elements which are regionally available, technologies associated to the seismic nature of the site and the current design tendencies in the architecture field. In the typical urban area, where pavements represent 40% of the enveloping surface near 15% corresponding to the pedestrian coatings (sidewalks) and 22 % to roofs (Correa et al, 2010).

The group of these factors gives rise to different expressions deriving from the idea of buildings both solid (bare brickwork, reinforced concrete) and liquid (steel and glass) structures, flat roofs and different colors, vertical surrounding areas, which cover a wide range of materials –bare brickwork, textured or flat scouring and heavy or light coating, flat or slanted, of tilings. Regarding urban areas, the areas of vehicle traffic share the outward appearance which shows most of the current cities - pavement, concrete- and pedestrian traffic – sidewalks- show a wide range of materials: These materials are concrete and stone, with clear colors in the past and a strong tendency to the use of dark colors nowadays. The geometry of Mendocinian city, the intense forestation of the traffic ways, which diminishes the available sky vision and the outward appearance of the surrounding areas, gives rise to the urban heat wave which reaches maximum values of de 10 ºC. This produces an increase in summer in the energy consumption of around 20% due to the cooling needs so as to obtain comfort conditions in the inner spaces of the metropolitan area. (Correa, et. al., 2006).

The work presented here classifies a Group of materials used in the surrounding areas of the city of Mendoza, Argentina, according to the method described by regulation ASTM E1980. The Solar Reflectance Index (SRI) of the selected materials, based on the measurement of its solar reflectivity, its thermal emissivity and its superficial temperature. In this way, also, it is possible to compare internationally the result of the operation of materials used locally and regionally, and at the same time, generate knowledge around the standardization of the regional materials, laying the foundations to propitiate a future energetic certification both at urban and civic level.

2. Objetivo

Determine the capacity to mitigate the negative effects of the Urban Heat Island of the different materials used regionally for the resolution of the surrounding areas (pavements, facades and roofs). By means of the categorization of the Solar Reflectance Index (SRI), so as to offer urban planners and local builders information about the thermal behavior of the alternatives which are available in the market.

3. Methodology

3.1. Sample unit

The selected sample corresponds to the building high density area, which is made up by the five main squares of the city: Independencia, Chile, San Martín, España and Italia squares, covering a Squire of 8x8has., which totals 64 blocks. (Fig.1)

The Mendocinian Metropolitan Area (AMM, according to Spanish acronym), is composed by a vertical dimension, defined by the height of the arboreal mass and the building facades, and by a horizontal dimension, corresponding to the mass of coatings, irrigation ditch network and traffic (pedestrian-vehicle). This report studies the thermo-physical behavior of pedestrian pavements, tiles and vertical coatings of facades.

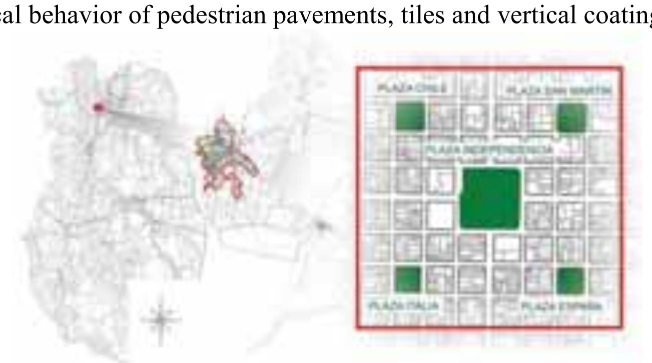


Fig.1: Location and characteristics of the sample space, within the Mendoza Metropolitan Area (AMM), Argentina.

3.2. Material selection and classification

From the survey of the vertical and horizontal surrounding areas of each of the portions contained in the sample unit, 140 materials that are more representative of the local civic park are selected. The sampling is made up by 16 coating coverings (tiles), 44 pedestrian pavements and 80 vertical coatings (acrylic and concrete). These are placed in a premise of CCT-Mendoza (Regional Center of Scientific and Technical Researches), located in the west area of the city.

The billings and pedestrian pavements were placed on a horizontal surface of 7cm thick of expanded polystyrene, acting as an adiabatic limit regarding the conductivity of the grounding material. So as to study the vertical coatings, blocks of 30x30 cm were built, formed by three layers: Support-isolation, additive and textured mortar. The first surface is a 10 cm thick plate of high-density expanded polystyrene. Secondly, a 3mm mortar is extended, enabling a better adherente to the coating to the polystyrene surface and, lastly, the layer of textured and colored coating. (Fig.2)

The pedestrian pavements were classified according to its form and sub-form: (straight - square, single line, diagonal multiline; circular -spider, fan, Andalucía; flat - mosaic, star, boulder); color: (gray, yellow, red, black, multicolor gray, multicolor red, multicolor black, Murcia black, Alicante bordeau, Jade green, black with sparks, travertine, multicolor); finish: (smooth, rustic pressing, textured washing); and composition (cementitious, cement-calcareous, cement-petreous, granitic)
Tiles were characterized according to its shape (colonial, French, Roman); color: (terracotta, gray, black); finish: (natural, matte, enameled, acrylic, glazy single and double firing, aged); and composition (concrete, clay).

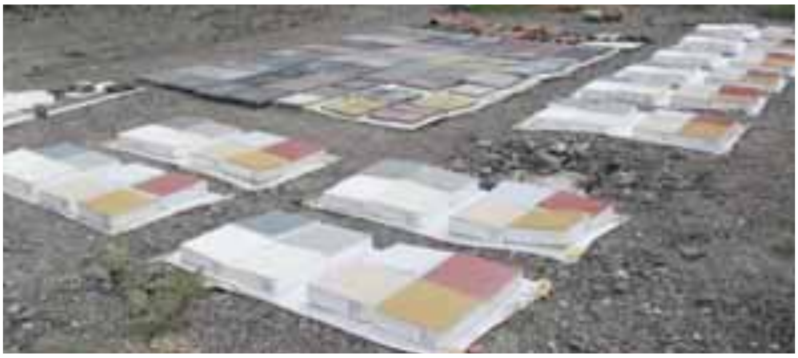
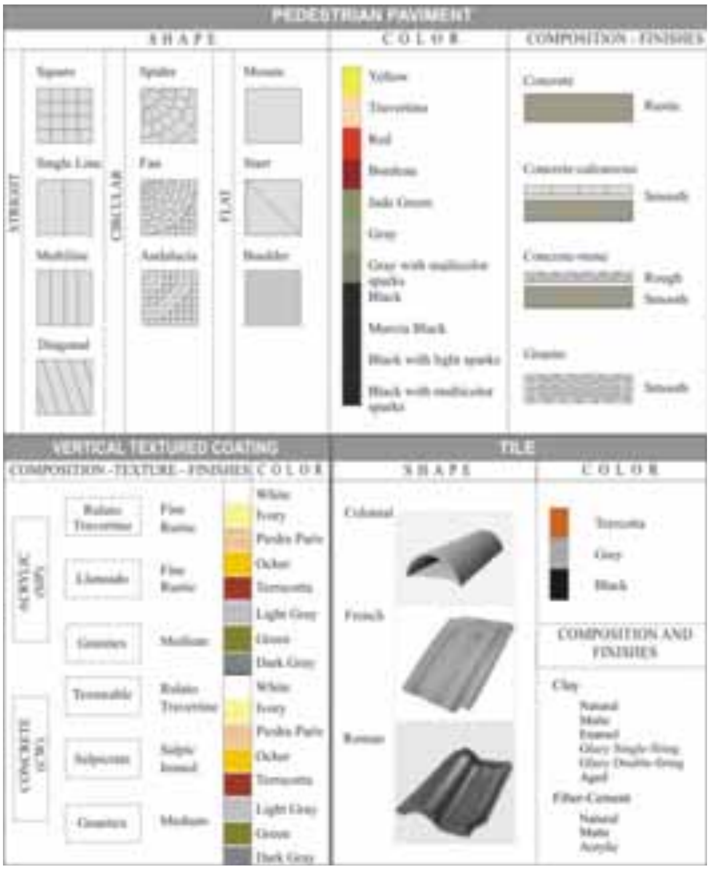


Fig. 2: Thermal and optic evaluation of the materials on site.

The textured coatings differentiated according to their composition in: acrylic (SIP) and concrete (CW). The first ones -SIP-(are quoted according to the manufacturer's labeling) are composed with acrylic polymers, mineral loads of multiple particle sizing, inorganic pigments with high UV resistance and chemical additives. The concrete mortars -CW- are composed with white concrete, spur stone, lime, pigments, organic and inorganic additives, mineral loads of classified particle sizing, synthetic resins, fungicides and algicides in powder, apt for using in coatings of walls and facades. In this stage, five texturas of different particle sizing and finish, for each composition according to the demand in the local market and use frequency. In the acrylic coatings- SIP: Travertine rolling both fine (rf) and thick (rg), smooth surface both fine (lf) and thick (lg), medium granitex (gm). In the concrete coatings- CW: textured rolling (tr) and travertine (tt), salpicrete salpic (ss) and ironed (sp), medium granitex (gm). In the 8 most-demanded colors: White, ivory, Paris stone, ochre, terracotta, clear gray, concrete gray, and lead gray. (Table 1).

Table 1: Material classification (tiles, pedestrian pavements, vertical coatings) according to its shape, composition, color and finish).



3.3. Instrumentation and description of the experience

The thermal performance of the materials is determined mainly by their optical and thermal characteristics, the albedo and the thermal emissivity, are the most important factors. (Doulos, Santamouris, Livada; 2004).

After a period of tests during the summer period of years 2010 and 2011, the albedo, emissivity and superficial temperature registries, corresponding to 13:00 hs were registered. These were used to calculate the SRI pursuant to what is established by the reference regulation in which this research is supported. The maximum value of registered solar radiation corresponds to 1006 W/m2, with an average temperature of air of 305,49ºK; and Relative Humidity of 23,4%. With maximum wind speeds near 2 m/s.

The IR chamber Fluke Ti 55 detects the infrared radiation of long wave in the range of 7,5 to 14 microns within the electromagnetic spectrum. With this instrument, thermal images were obtained, which register the radiant heat of each material. In thermographic pictures, each pixel contains a certain temperature value. The software Smart-View 2.1, through algorithms, assigns a specific color corresponding to a temperature value in the x-y coordinate of the image. (Fig.2). Due to the lack of uniformity of the superficial temperatures of the same studied material, the values correspond to the average amount of the total horizontal surface. The scarce uniformity is mainly due to a concentration of pigmentation in some areas, different rugosities of a same texture or composition. (Fig.3).

3.4. Calculation of emissivity, albedo and Solar Reflectance Index (SRI)

The radiant energy which is registered by the infrared chamber does not only depends on the object temperature, but on its emissivity (ε) which was set according to the value measured for each material. This information is obtained by means of the comparison between the T type thermal registry, associated to a HOBBO data logger, and the superficial temperature that is measured by a IR thermometer Fluke 568 with emissivity adjustment. (ASTM Standard, 2006).

A Kipp&Zonen C3 type albedometer was used to determine the albedo value (α). This instrument registers the solar radiation which is received over the horizontal surface and the reflected solar radiation, and in this way, the albedo of each coating is determined by difference.
The thermal conductivity has not been considered, since the thicknesses are similar among each other and, also, the work is performed with an expanded polystyrene as adiabatic limit regarding the grounding conductivity.

The Solar Reflectance Index (SRI) quantifies the heat which would accumulate a material related to a white and a black pattern surface under standard environmental conditions. This method is used for surfaces with emissivities higher than 0,01 and superficial temperatures lower than 150 ºC. (ASTM Standard 2011).
The index enables a direct comparison between the materials of the urban surrounding areas with different optical properties (albedo and emissivity). By determining efficiency and effectiveness of each of them, the negative effects of the heat island (UHI) are mitigated.

3.5. Solar Reflectance Index (SRI)

It is calculated by using equations based on information that is previously defined and measured of reflectance and solar emittance, and it is expressed as a value (0, 0 to 1,0) or as a percentage (0% to 100%). For a surface exposed to sun and isolated underneath, the superficial temperature of Ts equilibrium is obtained as from (ASTM E1980-11). Where:

α = solar absorptance = 1 − solar reflectance,
I = solar flux, $W \cdot m^{-2}$,
ϵ = thermal emissivity,
σ = Stefan Boltzmann constant, 5.66961 x 10^{-8} $W \cdot m^{-2} \cdot K^{-4}$,
T_s = steady-state surface temperature, K,
T_{sky} = sky temperature, K,
h_c = convective coefficient, $W \cdot m^{-2} \cdot K^{-1}$, and
T_a = air temperature, K.

$$Ts=309.07+\frac{(1066.07\alpha-31.98\varepsilon)}{(6.78\varepsilon+h_c)}-\frac{(890.94\alpha^2+2153.86\alpha\varepsilon)}{(6.78\varepsilon+h_c)^2}$$
(eq. 1)

Therefore, the Solar Reflectance Index is defined as:

$$SRI = 100\frac{T_b-T_s}{T_b-T_w}$$
(eq. 2)

By means of equation 1, the superficial temperatures of the patters are calculated (white -Tw- and black -Tb-), under local environmental conditions, according to regulations. (Table 3)

Table 3: SRI values of pattern surfaces.

Patterns	â	ε	Ts (Kº)	SRI (%)
Tw	0.80	0.90	354.8	0
Tb	0.05	0.90	310.3	100

Once the patterns were obtained, the solar reflectance indexes (SRI) were determined for each coating (pedestrian, covering and facade). The information was calculated by means of the use of equation 2. (Table 4.5.6)

Table 4: Assigned code, superficial temperature (ºK), albedo, emissivity and SRI of pedestrian pavements.

	PEDESTRIAN PAVIMENT	â	ε	Ts (ºK)	SRI (%)		PEDESTRIAN PAVIMENT	α	ε	Ts (ºK)	SRI (%)
P01	Concrete fan circular gray rustic	0.53	0.90	340.05	33.15	P20	Concrete square stringht gray rustic	0.56	0.90	337.45	38.99
P02	Concrete spider circular black rustic	0.49	0.95	341.85	29.10	P21	Concrete -stone andalucía circular jade green smooth	0.51	0.95	340.45	32.25
P03	Concrete andalucía circular red rustic	0.53	0.95	338.55	36.52	P22	Concrete -stone square stright black with light sparks smooth	0.47	0.95	343.15	26.18
P04	Concrete fan circular red rustic	0.56	0.90	337.95	37.87	P23	Concrete -stone andalucía circular Murcia black smooth	0.48	0.90	343.75	24.83
P05	Concrete fan circular black rustic	0.47	0.95	343.35	25.73	P24	Concrete -stone square stright bordeau smooth	0.55	0.90	338.25	37.19
P06	Concrete -stone Boulder flat gray rustic	0.56	0.90	337.95	37.87	P25	Concrete -stone mosaic flat gray with multicolor sparks smooth	0.64	0.85	332.55	50.00
P07	Concrete square stright black rustic	0.43	0.95	345.65	20.56	P26	Concrete -stone andalucía circular black with multicolor sparks smooth	0.48	0.90	343.45	25.51
P08	Concrete spider circular gray rustic	0.55	0.90	338.15	37.42	P27	Concrete andalucía circular black rustic	0.42	0.98	345.65	20.56
P09	Concrete spider circular red rustic	0.54	0.90	339.05	35.39	P28	Concrete -stone square stright red with multicolor sparks smooth	0.54	0.90	339.55	34.27
P10	Concrete -stone fan circular murcia black smooth	0.47	0.95	343.35	25.73	P29	Granite flat mosaic Murcia black smooth	0.46	0.90	345.25	21.46
P11	Concrete -stone andalucía circular black with light sparks smooth	0.48	0.90	343.65	25.06	P30	Concrete -stone square stright gray with multicolor sparks smooth	0.57	0.90	337.15	39.66
P12	Concrete -stone square stringht murcia black smooth	0.46	0.95	344.05	24.16	P31	Granite mosaic flat jade green smooth	0.51	0.90	341.15	30.67
P13	Concrete -stone andalucía circular gray with multicolor sparks smooth	0.62	0.85	334.45	45.73	P32	Concrete -stone square stright jade green smooth	0.46	0.90	345.45	21.01
P14	Concrete diagonal stright yellow rustic	0.55	0.90	338.75	36.07	P33	Concrete square straight black rustic	0.45	0.95	344.75	22.58
P15	Concrete mosaic flat red rustic	0.52	0.95	339.35	34.72	P34	Granite mosaic flat travertine smooth	0.76	0.80	322.85	71.80
P16	Concrete -stone boulder flat multicolor rough	0.55	0.90	338.45	36.74	P35	Concrete-calcareous single line stright black smooth	0.42	0.95	346.45	18.76
P17	Concrete start flat yellow rustic	0.54	0.90	339.25	34.94	P36	Concrete-calcareous single line stright red smooth	0.53	0.90	339.95	33.37

P18	Concrete start flat gray rustic	0.57	0.90	336.45	41.24	P37	Concrete-calcareous single line stright yelow smooth	0.54	0.90	339.35	34.72
P19	Concrete mosaic flat black rustic	0.44	0.95	345.05	21.91	P38	Concrete-calcareous multiline stright yellow smooth	0.54	0.90	339.25	34.94

Tab.5: Assigned code, superficial temperature (ºK), albedo, emissivity and SRI of tiles.

TILE		â	ε	*Ts (ºK)*	SRI (%)	TILE		â	ε	*Ts (ºK)*	SRI (%)
T01	Clay Colonial terracotta natural	0.64	0.90	328.55	58.99	T09	Clay Roman terracotta natural	0.58	0.90	332.15	50.90
T02	Clay French terracotta natural	0.60	0.90	331.15	53.15	T10	Clay Roman terracotta age	0.58	0.94	331.85	51.57
T03	Clay French terracotta enamel	0.64	0.90	328.55	58.99	T11	Fiber-Cement Colonial terracotta natural	0.50	0.95	336.45	41.24
T04	Clay French black glazy double-fire	0.50	0.95	336.35	41.46	T12	Fiber-Cement French black matte	0.44	0.95	339.95	33.37
T05	Clay French black glazy single-fire	0.48	0.98	337.25	39.44	T13	Fiber-Cement French black acrylic	0.40	0.95	341.95	28.88
T06	Clay French black matte double-fire	0.49	0.98	336.65	40.79	T14	Fiber-Cement French gray natural	0.63	0.90	328.95	58.09
T07	Clay French black matte single-fire	0.48	0.95	337.45	38.99	T15	Fiber-Cement Colonial black matte	0.53	0.95	334.25	46.18
T08	Clay Roman terracotta enamel	0.67	0.85	326.95	62.58	T16	Fiber-Cement Colonial terracotta matte	0.57	0.95	332.15	50.90

Tab.6: Código asignado, temperatura superficial (ºK), albedo, emisividad y SRI de revestimientos verticales texturados.

FACADE CLADDING		â	ε	*Ts (ºK)*	SRI (%)	FACADE CLADDING		â	ε	*Ts (ºK)*	SRI (%)
SIP 01	Fine travertine rulato withe	0.86	0.85	311.75	96.68	CW 41	Rulato texturable withe	0.86	0.90	311.45	97.35
SIP 02	Fine travertine rulato ivory	0.91	0.90	308.25	100.00	CW 42	Rulato texturable ivory	0.77	0.85	316.65	85.68
SIP 03	Fine travertine rulato fine Paris stone	0.81	0.88	314.35	90.84	CW 43	Rulato texturable paris stone	0.69	0.80	321.95	73.78
SIP 04	Fine rulato travertine fine ochre	0.47	0.95	332.35	50.44	CW 44	Texturable rulato ochre	0.51	0.85	331.65	52.01
SIP 05	Fine rulato travertine fine terracotta	0.41	0.95	335.75	42.80	CW 45	Rulato texturable terracotta	0.49	0.93	331.65	52.01
SIP 06	Fine rulato travertine fine light gray	0.57	0.85	328.65	58.74	CW 46	Rulato texturable light gray	0.61	0.82	326.65	63.23
SIP 07	Fine rulato travertine fine green	0.40	0.95	336.35	41.46	CW 47	Rulato texturable green	0.42	0.95	335.15	44.15
SIP 08	Fine rulato travertine fine dark gray	0.28	0.95	342.35	27.99	CW 48	Rulato texturable dark gray	0.32	0.95	340.45	32.25
SIP 09	Rustic rulato travertine withe	0.78	0.85	316.15	86.80	CW 49	Travertine texturable withe	0.53	0.85	330.85	53.80
SIP 10	Rustic rulato travertine ivory	0.86	0.90	310.95	98.47	CW 50	Travertine texturable ivory	0.76	0.85	317.65	83.43
SIP 11	Rustic rulato travertine Paris stone	0.82	0.90	313.55	92.64	CW 51	Travertine texturable paris stone	0.69	0.90	321.05	75.80
SIP 12	Rustic rulato travertine ocrhe	0.42	0.95	335.15	44.15	CW 52	Travertine texturable ochre	0.60	0.90	326.15	64.35

SIP 13	Rustic rulato travertine terracotta	0.29	0.94	341.95	28.89
SIP 14	Rustic rulato travertine light gray	0.47	0.95	332.75	49.54
SIP 15	Rustic rulato travertine green	0.37	0.95	337.95	37.86
SIP 16	Rustic rulato travertine dark gray	0.29	0.95	342.05	28.66
SIP 17	Fine llaneado withe	0.81	0.80	315.05	89.27
SIP 18	Fine llaneado ivory	0.48	0.85	333.35	48.19
SIP 19	Fine llaneado Paris stone	0.91	0.90	308.55	100.00
SIP 20	Fine llaneado ocrhe	0.83	0.90	313.05	93.76
SIP 21	Fine llaneado terracotta	0.39	0.95	336.95	40.11
SIP 22	Fine llaneado light gray	0.76	0.90	317.25	84.33
SIP 23	Fine llaneado green	0.35	0.95	338.55	36.52
SIP 24	Fine llaneado dark gray	0.19	0.95	346.75	18.11
SIP 25	Rustic llaneado withe	0.83	0.85	313.55	92.64
SIP 26	Rustic llaneado ivory	0.73	0.85	319.25	79.84
SIP 27	Rustic llaneado Paris stone	0.54	0.85	330.05	55.60
SIP 28	Rustic llaneado ochre	0.72	0.90	319.25	79.84
SIP 29	Rustic llaneado terracotta	0.46	0.95	332.95	49.09
SIP 30	Rustic llaneado light gray	0.73	0.90	318.85	80.74
SIP 31	Rustic llaneado green	0.30	0.95	341.35	30.23
SIP 32	Llaneado rustic dark gray	0.23	0.95	344.75	22.60
SIP 33	Medium granitex withe	0.86	0.85	311.65	96.90
SIP 34	Medium granitex ivory	0.76	0.85	317.65	83.43
SIP 35	Medium granitex Paris stone	0.65	0.85	324.05	69.07
SIP 36	Medium granitex ochre	0.70	0.90	320.35	77.37
SIP 37	Medium granitex terracotta	0.39	0.95	336.55	41.01
SIP 38	Medium granitex light gray	0.46	0.92	333.75	47.29
CW 53	Travertine texturable terracotta	0.44	0.95	334.15	46.39
CW 54	Travertine texturable light gray	0.68	0.90	321.75	74.23
CW 55	Travertine texturable green	0.50	0.90	331.85	51.56
CW 56	Travertine texturable dark gray	0.46	0.90	334.05	46.62
CW 57	Salpic salpicrate withe	0.80	0.85	315.15	89.04
CW 58	Salpic salpicrate ivory	0.79	0.90	315.15	89.04
CW 59	Salpic salpicrate paris stone	0.66	0.90	322.65	72.21
CW 60	Salpic salpicrate ochre	0.55	0.95	328.15	59.86
CW 61	Salpic salpicrate terracotta	0.57	0.90	327.65	60.99
CW 62	Salpic salpicrate light gray	0.70	0.85	321.25	75.35
CW 63	Salpic salpicrate green	0.48	0.90	332.85	49.31
CW 64	Salpic salpicrate dark gray	0.33	0.90	340.65	31.80
CW 65	Ironed salpicrate withe	0.83	0.80	313.55	92.64
CW 66	Ironed salpicrate ivory	0.73	0.85	319.15	80.06
CW 67	Ironed salpicrate paris stone	0.60	0.85	326.85	62.78
CW 68	Ironed salpicrate ochre	0.48	0.95	332.05	51.11
CW 69	Ironed salpicrate terracotta	0.44	0.95	334.05	46.62
CW 70	Ironed salpicrate light gray	0.65	0.85	324.05	69.07
CW 71	Ironed salpicrate green	0.46	0.90	334.05	46.62
CW 72	Salpicrate ironed dark gray	0.31	0.95	341.05	30.91
CW 73	Medium granitex withe	0.81	0.85	314.35	90.84
CW 74	Medium granitex ivory	0.75	0.85	317.85	82.98
CW 75	Medium granitex Paris stone	0.72	0.90	319.65	78.94
CW 76	Medium granitex ochre	0.49	0.90	332.15	50.88
CW 77	Medium granitex terracotta	0.49	0.90	332.25	50.66
CW 78	Medium granitex light gray	0.70	0.80	321.55	74.68

SIP 39	Medium granitex green	0.34	0.95	339.25	34.95	**CW 79**	Medium granitex green	0.45	0.90	334.45	45.72
SIP 40	Medium granitex dark gray	0.26	0.95	343.35	25.74	**CW 80**	Medium granitex dark gray	0.69	0.95	320.45	77.15

4. RESULTS

4.1. Pedestrian Paviment: Analysis of the thermal behavior and the SRI according to classification

- Comparison between extreme cases: Out of the studied pedestrian pavements, the material mostly favoring the mitigation of the Urban heat island is the *Granite mosaic flat travertine smooth* -P34- with a superficial temperature of 322, 85ºK and a SRI equal to 71, 80%; in second and third place, the *Concrete -stone mosaic flat gray with multicolor sparks smooth* -P25- y el *Concrete -stone andalucía circular gray with multicolor sparks smooth* -P13 are located. The pavements that contribute the less to the reduction in the thermal loads of the city are in ascending order. the *Concrete-calcareous single line straight black smooth* -P35- with a superficial temperature of 354, 8ºK and a SRI of 18, 76%; then, we find the *Concrete square straight black rustic* -P07-; and finally, *Concrete andalucía circular black rustic* -P27.

That is, that between the two extreme cases that are analyzed the pavement *travertine granite*, has 53% more of capacity to mitigate the effects of the heat island than *black concrete-calcareous*. Its thermal difference is 23,06ºK. (Fig.3).

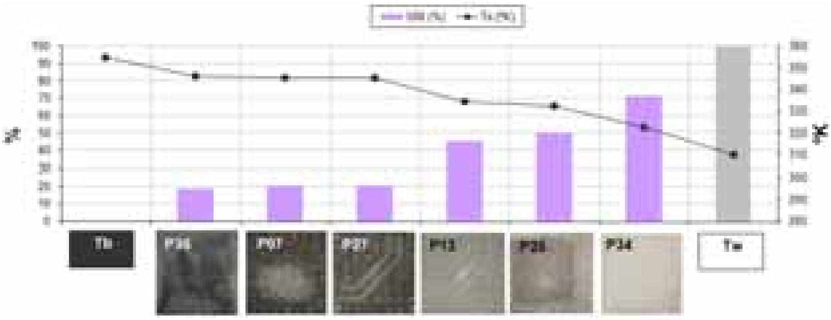


Fig. 3: Solar Reflectance Index of Pedestrian Pavements. (Only the three materials having higher and lower capacity to decrease the ICU respectively are drawn)

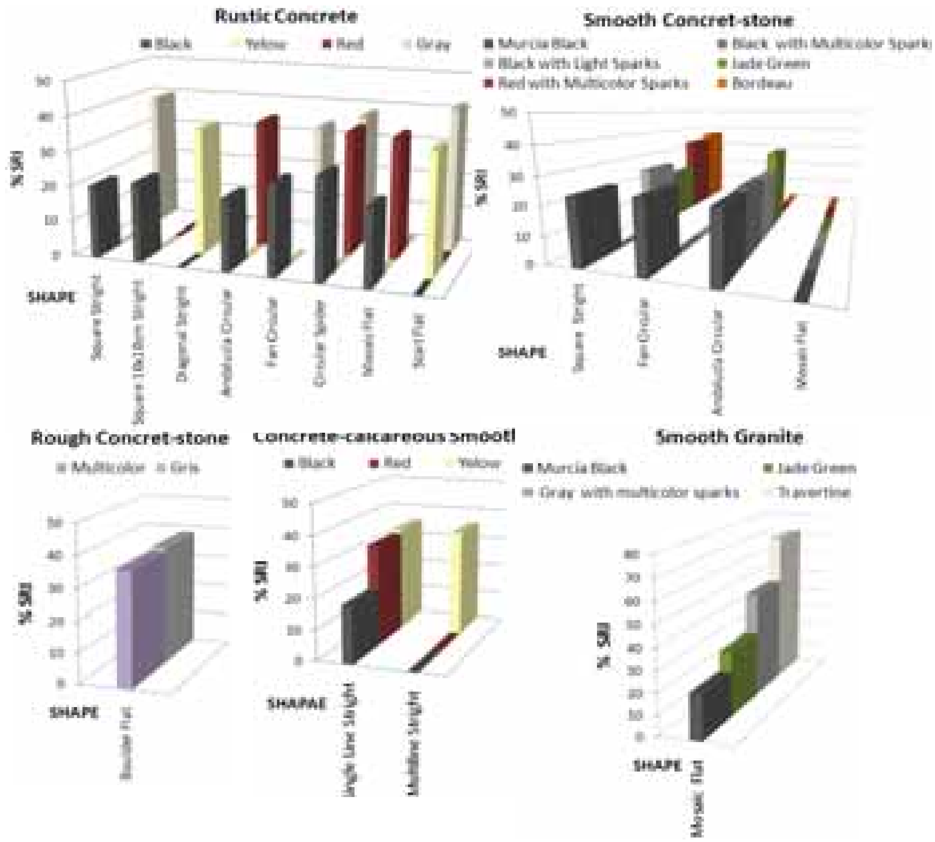


Fig. 4: Solar Reflectance Index of Pedestrian Pavements, grouped according to its composition.

- Differences by Constituents and color: When comparing the straight pedestrian coatings, single line of higher diffusion within the AMM (calcareous tile) of color: *red* -P36- *black* -P35- and *yellow* -P37-, is obtained as a result than the floor *black* -P35- is the one reaching higher temperatures. Its temperature is 6, 5 ºK higher than the calcareous *red*, and 7, 1ºK higher than the *yellow* one. The *black* floor obtains an index of 18, 76%, while the *red* and *yellow* tiles reach values of 33,37% and 34,72% respectively. That is, that the options *yellow* and *red* do not show significant differences of superficial temperature between them.
The *boulder* floor was detected within the AMM in a second frequency order. When comparing the floor *Concrete-stone boulder rustic*, *gray* color -P6-, with the *Concrete-stone rustic multicolor* -P16-, the first one reaches a temperature of 337, 95ºK, while the *multicolor* registered 338,45ºK, proving that, in this pavement, the color difference does not condition substantially its thermal behavior. The SRI values are de 36,74%, for the case and of 37,87% in the second one.
Among the *flat mosaic granite* floors, 4 cases of different colors were studied: *travertine* -P34-, *multicolor gray* -P25-, *jade green* -P31-, and *murcia black* -P29. It was observed that *murcia black* registers the highest temperatures. Its value is 22,4 ºK higher than in *travertine*, 12,7ºK ºK higher than in the gray coating, and 4,1 ºK higher than in *jade green* color. *Travertine* floor reaches a reflectance index of 71,8%, while *murcia black* does not exceed 21,01%.

- Differences by Shape: It is observed that *concrete black* floor, *rustic spider circular* type -P2-, increases its temperature less related to the *square straight* coating -P7- and *flat mosaic* -P19-. For a same color and finish, the difference exceeds 3,8ºK. It has a reflectivity value ranking from 20% and 29% in the most favorable option. (Fig.4)

4.2. Tiles: Analysis of the thermal behavior and the SRI according to classification

- Comparison between extreme cases: In the case of materials for coating, three types of tiles are detected, with higher capacities so as to decrease the heating charges in the city. These are: tile *Clay Roman terracotta enamel* -T08- with a surface temperature of 326,95ºK and SRI equal to 62,58%; in second and third place, we have tile *Clay French terracotta enamel* -T03-, and *Clay Colonial terracotta natural* -T01. (Fig.6)
The coating coverings which contribuye to ICU formation are: tile *Fiber-Cement French black acrylic* -T13-, with a surface temperature of 341ºK and SRI of 28,88%; *Clay Roman terracotta natural* -T09-, and lastly, *Fiber-Cement French black matte* -T12. (Fig.5)
Tile *clay roman terracotta enamel* increases 15ºK less than *Fiber-Cement Colonial terracotta matte*; reaching 33,7 % of solar reflectivity.

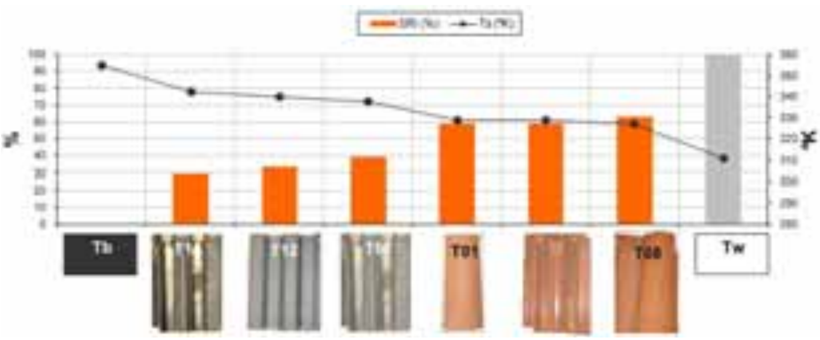


Fig.5: Solar Reflectivity Index of Tiles. (Only the three materials having higher and lower capacity to decrease the ICU respectively are drawn)

- Composition difference: Tiles *clay* show a better thermal performance than f*iber-cement* ones, for example: Tile *colonial terracotta clay* -T01- behaves better than f*iber-cement* one -T16-. Temperature differences between both options exceed 3,6ºK. *Clay* tile has a Solar Reflectance Index of 59%, while f*iber-cement* one reaches 50%.

- Difference in *finishes:* In the case of *french tile*, the capacity of the material *clay* to decrease the heating loads is evidenced. Tail *clay black matte double fire* -T06-increases less its temperature than *clay black matte single fire* -T07-. The temperature difference reaches 3,3ºK and an index not exceeding 40,29%, in the coldest option.
Tile *roman terracotta clay natural* -T09- increases its temperature 5,2 ºK over *enamel* one -T08-. Solar reflectance in the enamel option exceeds 62%.
In the tiles of *Fiber-Cement Colonial terracotta, matte finish* (Ts=335,15ºK) has a coldest behavior than the *natural* finish (Ts=336,45ºK), the indicator reaches a difference of 9% higher than in *matte* tile.

- Difference in color*:* *Black* tiles show a higher surface temperature. In the tile *French Fiber-Cement matte black* -T12- reaches 339,95ºK, while temperature in *gray* -T14-is 11,4ºK lower. The indicator value is 58,09% in the *gray* one and 33,37% in the *black* one.

- Difference in form: According to its classification by shape *romans* tiles of different colors and finishes reach average temperatures of 326 and 332ºK, while *colonial* tile covers a range between 328º and 334ºK ; and *french* ones, 328 and 341ºK. For example, tile *Fiber-Cement French black matte* -T12- increases its temperature 5,7 ºK more than *colonial* one -T15-. Levels of SRI 12,81% higher are obtained in the *colonial* tile. (Fig.6).

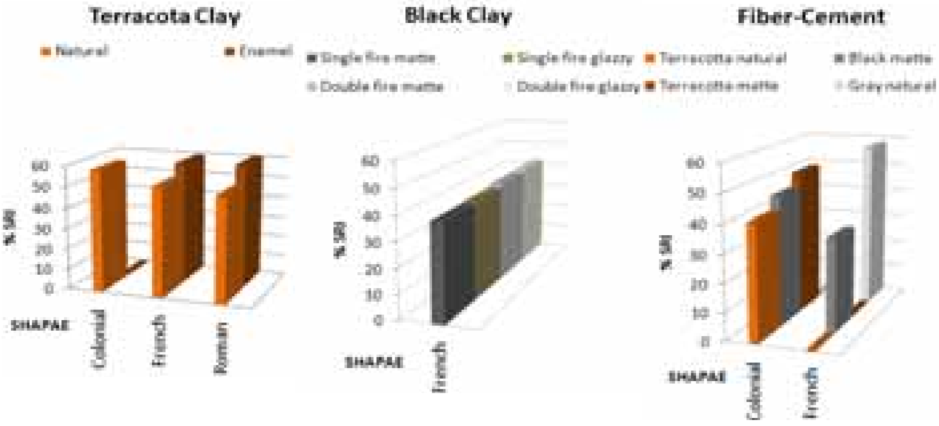


Fig. 6: Solar Reflectance Index of Tiles, grouped according to its composition.

4.3. Facade Cladding: Analysis of the thermal behavior and the SRI according to classification

- Comparison between extreme cases *by constituents* (SIP-CW): In the acrylic coatings (SIP), the material which has more capacity to decrease the heating loads within the city is *Fine rulato travertine ivory* -SIP02- with a surface temperature of 308,3ºK and a SRI of 100%; and secondly, we have *Fine smooth parís stone* -SIP19- which registers a surface temperature of 308,6ºK.

The acrylic cladding (SIP) which show an unfavorable behavior are: the *Fine smooth dark gray* -SIP24- with a surface temperature of 346,8ºK and a SRI of 18% and the *Rustic smooth dark gray* -SIP32, with a solar reflectivity lower than 23%. That is, that between the two extreme cases that are analyzed the coating *Ivory rulato*, has values higher than 80% of capacity to mitigate the effects of the heat island than *Smooth dark gray*. Its thermal difference is 39ºK.

In the case of the concrete materials (CW) the *facade cladding* which does not increase much its temperature is *Rulato textured White* -CW41- with a registry of 311,45ºK and SRI of 97%. The *Ironed salpicrate white* -CW65- is located in second place, with 93% of solar reflectivity. Out of the total of monitored cementitious samples, the main materials which increase the thermal loads within the city are: the *Ironed salpicrate dark gray* -CW72- with a surface temperature of 341,05 ºK and a SRI of 31%; and then we have the *Salpic salpicrate dark gray* -CW64.
The *facade cladding White* t*exturable* -CW41- increases 30ºK less than *Dark gray* s*alpicrate* -CW72-; with a reflective difference of 66%.

- Differences of color in *Acrylic cladding* (SWP): When modifying the color in the texture *Fine travertine rulato*: *White* color -SIP01- reaches a temperature of 311,8ºK, while the hottest alternative, *dark gray* material -SIP08-reaches up to 342,4ºK. That is, surface thermal differences of 30,01ºK were assessed, with a SRI of 98% in the coldest case.
The coldest *travertine rustic rulato* is of evory tone -SIP10, while the color which more increases the temperature is *dark gray* -SIP16. Here, a surface thermal difference of 25,9ºK is observed.
Within the smooth surfaces, the fine finish of *paris stone* color -SIP19- is the one which reaches its temperature the less, reaching a SRI 100%. *White* color shows a better performance to decrease the negative effects of ICU, in the textures: *Smooth Rustic*-SIP 25-(SRI=93%) and *Medium grantix* -SIP 33- (SRI=97).

Ivory color, *Fine smooth* -SIP 18- behaves negatively when decreasing the heat loads. Measurements register a temperature of 333,4ºK and a solar reflectivity index that is lower than in the remaining configurations. It means that, in the texture *Fine smooth*, the behavior of *ivory* -SIP 18- turns to be notably unfavorable compared to the samples of equal texture and finish of *paris stone* color -SIP 19- and pearl gray -SIP 22.
The difference of SRI of paris stone material -SIP19 with dark gray -SIP22 reach 52% plus solar reflectivity, compared to the coldest material: SIP 22. (Figure 8).

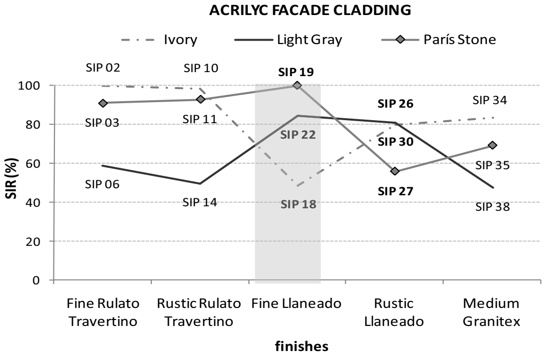


Fig. 8: Cladding Ivory fine smooth, Light gray and parís stone and their capacity to decrease the cooling loads.

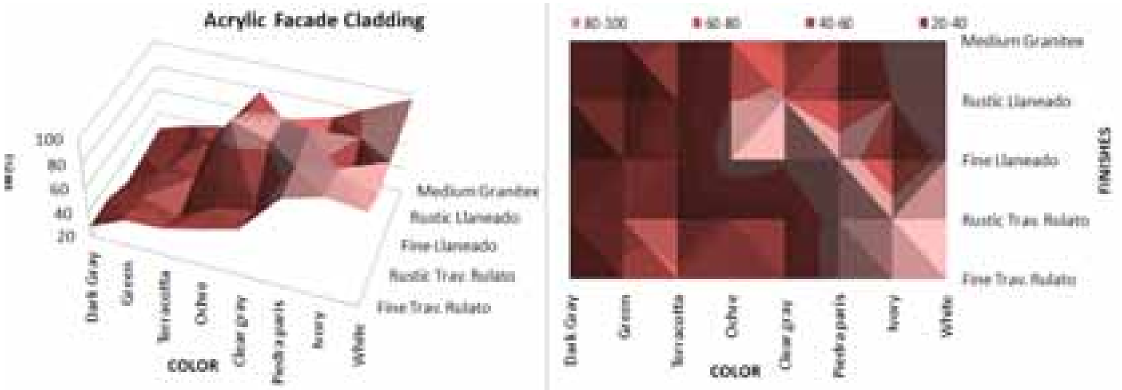


Fig. 9: SRI of Acrylic facade cladding, according to classification.

<u>- Differences of *Texture-Finishes* in *Acrylic cladding*</u>: The fine finish shows a good behavior in the textures *Travertine Rulato* and *Smooth*, for colors *ochre*, *parís stone* and *green*. There are maximum reflection indexes in *parís stone* material -SIP19; and thermal differences with the option *rustic* -SIP27- of 21,5ºK. On the other hand, in *dark gray* tonality, the finish *rustic* of *Rulato* and *Smooth* is more efficient.

For example, coating *smooth fine* -SIP 24-, reaches 2 ºK more its surface temperature than thick granulometry -SIP32. In colors: *white*, *terracotta* and *ivory*, the finish which shows the best performance depends on the texture: For the *Smooth surface,* the finish *rustic* is the coldest; on the other hand, in the *Rulato,* is *fine*. This is the case of coating *Ivory rustic smooth* -SIP 26-, registers maximum values of SRI of 79,8% and a superficial thermal difference of 14,1ºK with an alternative *fine* -SIP18. (Figure 9).

<u>- Differences of Color in *Concrete cladding*</u>: The tonalities *white* and ivory show the capacity of clear materials to decrease the cooling loads. They reach an average solar reflection index of 85%, for both colors, in all textures.
When comparing two extreme tonalities in *Rulato Texturable* in coatings *white* -CW41- and *dark gray* -CW48-; the temperature differences reach 29ºK. It has a solar reflectivity index of 97,35% in the clearest option. (Fig.10).

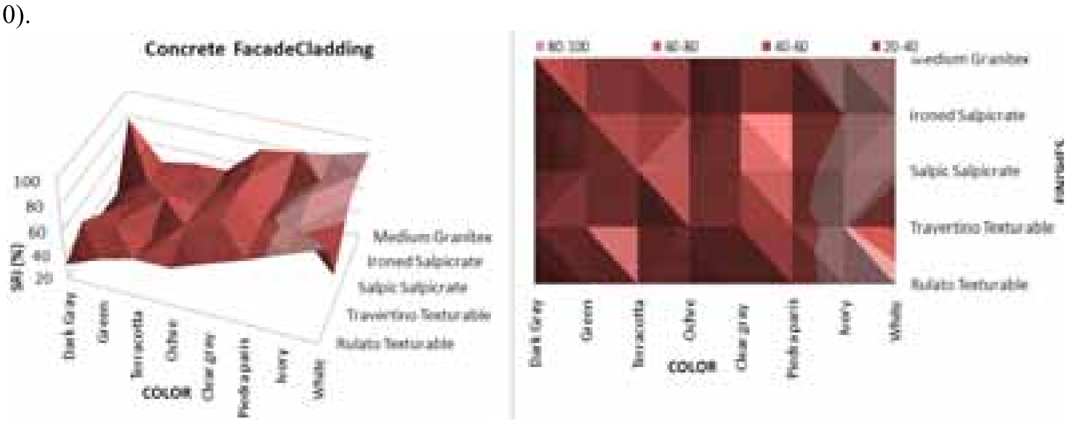


Fig. 10: SRI of Concrete facade cladding, according to classification.

<u>- Differences of *Texture-Finishes* in *Concrete claddding*</u>: With an average of 69%, the *medium granitex* is the texture reaching the highest levels of solar reflectivity. The capacity of *White texturable travertine* -CW49-, is lower than the rest of the finishes in the abovementioned color, with a refectance index not exceeding 54%. In the rest of the textures, *white* tonality reaches an average of 92%.

When modifying the characteristics of material texture and finish, the *ivory and green* pigmentation are the ones showing higher thermal stability when modifying the finish characteristics.
In colors i*vory, parís stone, ochre, terracotta, light gray, green and dark gray*; texture *Salpic salpicrate,* not increase much the temperature than the one of ironed finish. When contrasting the coating *Salpic salpicrate terracotta* -CW61- with the *Ironed salpicrate terracota* -CW69-, salpic material is the coldest. The differences are: 6,4ºK and 14,37% of SRI.

5. CONCLUSIONS

The selection of the appropriate coatings must not be a random decision. It turns to be a valuable strategy to decrease the heating loads in coverings, welding and vertical coatings. The color selection is vital since, for a same composition, finish, form and texture, percentages of reflectivity were detected, oscillating between 53 and 72% in the pedestrian coatings and from 53 to 58% in the tiles.

If the requirements of design and/or project require the addition of black coatings, it is convenient to choose the stone pedestrian pavements, instead of the rustic ones, since rugosity reduces all the reflected energy (Chimkla et al, 2004). It also happens in the coating, where the options are tiles of enamel or natural finish instead of matte ones. It is important to clarify that the superficial treatment of enamel is lost with time, until it seems like a tile without treatment, as in the case of natural one.
Among the clear pavements, such as travertine or yellow, it is recommended the use of smooth finishes, such as granite travertine. The existence of clear sparks within the granite mosaics contributes to decrease the surface temperatures, among samples of a same color.
On the other hand, in the tiles, the aged finishes increase the heating loads of the material.

Regarding the shape, we see that, in spite of keeping the material composition, color, texture and finish constant, decreases of temperature of 3,8ºK were obtained for coatings of circular configuration.
In the tiles, the use of Roman typology instead of colonial or French typology is recommended, since differences of percentages of solar reflectivity higher than 13% are reached.

In the *facade cladding*, the impact of color in the surface temperature of a acrylic material with the same characteristics is remarkable. Between white and dark gray, differences of surface temperature were registered for all the textures and finishes, which exceed 26ºK and reach levels of 70% more of solar reflectivity in the clearest options.

Particular attention must be paid to the texture *Fine smooth,* since the color *ivory* turns out to be very unfavorable, with 48% of solar reflectivity. For this type of texture, the use of Paris stone or light gray tonalities is recommended. In addition, the thermal behavior of the *acrilyc cladding* turns out from the combination of texture, finish and color. This variable relationship generates many aesthetic alternatives against design. On the other hand, in the coatings of *concrete* composition, the dominant factor to achieve efficiency is the color.

These results support the importance of scheduling in a thermic way the materials that are available regionally for the resolution of the surrounding areas so as to transfer this information to the persons in charge of the habitat development as a tool for the sustainable development of a city.

6. REFERENCES

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