Proceedings of Conference: ***Adapting to Change: New Thinking on Comfort***
Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Spectral behaviour of cool paints produced in Brazil for roof paint and their impact on the thermal comfort and energy use in buildings designed for hot climates

Kelen Dornelles[1*]; Victor Roriz[2]; Maurício Roriz[3]; Rosana Maria Caram[1]

[1] Department of Architecture and Urbanism, Sao Carlos Engineering School, University of São Paulo, Brazil.

[2] Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Planning, University of Campinas, Brazil;

[3] Department of Civil Engineering, Federal University of Sao Carlos, Brazil.

*E-mail: kelend@terra.com.br

Abstract:
This paper presents the evaluation of cool and reflective paints produced in Brazil and their impact on the thermal comfort in no-conditioned buildings located in the city of Belem, Brazil. In order to characterize the thermal performance of these materials, reflective and cool paints produced in Brazil for roof paint were evaluated in this research, as well as correspondent conventional coatings. Spectral reflectances were measured using a spectrophotometer for the solar spectrum from 300 to 2500 nm. In order to indicate the impact on the thermal comfort conditions in no-conditioned buildings located in Brazil, computer simulations were performed for a residential building using the EnergyPlus simulation software, according to reflectance data obtained with the spectrophotometer, and the comfortable temperature intervals according to ASHRAE 55-2004 for natural ventilated buildings. The results showed that the use of reflective coatings for cooling the roof surfaces is efficient in reducing the discomfort by heat inside buildings located in tropical climates.

Keywords: solar reflectance, cool paints, thermal comfort, cool roofs.

1. Introduction:

In tropical areas, solar radiation is the main responsible for the thermal load of buildings. In this case, the most efficient way to reduce heat gains of buildings is to control and minimize the solar radiation absorbed by the building envelope. The heat flow between outdoor and indoor will depend on the building envelope and the thermal and physical properties of building elements (DORNELLES; RORIZ, 2004).

From the total of the solar radiation that hits an opaque surface, part is reflected and another one is absorbed. The absorbed fraction is transformed into heat and it is proportional to a body surface property called absorptance (α). The reflected portion is obtained by the surface reflectance (ρ). For opaque surfaces, the sum of the absorptance and reflectance is the unity. Therefore, the solar reflectance (ρ) is defined as the ratio of the solar energy reflected by the surface to the total of the incident solar energy. This characteristic of an opaque surface can be considered as a criterion in designing the building envelope, which affects the choice of the exterior surface material.

According to Givoni (1998), building envelope reflectances determine the impact of solar radiation in buildings, once they indicate which portion of the solar energy that hits the building envelope is actually absorbed by the exterior surface, affecting the building's heat gains and indoor temperatures, and which part is reflected, with no effect on the building thermal conditions. The heat gains of building opaque surfaces due to solar radiation affect the indoor thermal comfort conditions and consequently the energy consumption increase in conditioned buildings or the thermal discomfort in no-conditioned buildings.

It was demonstrated in several experimental studies and computer simulations that building envelopes with high solar reflectance can considerably lower indoor air temperature of individual ones, and in the meso-scale, lower urban ambient temperatures which, in turn, improve the problem of urban heat island (GIVONI, 1998; TAHA et. al., 1988).

According to Synnefa, Santamouris and Akbari (2007), increasing the solar reflectance lowers a surface's temperature since solar radiation is reflected rather than absorbed. In turn, this decreases the heat penetrating into the building. During the summer, it results in lower cooling loads if it is an air-conditioned building or in more comfortable thermal conditions if the building is not air-conditioned. The large-scale use of cool materials in urban areas leads also to indirect energy savings due to the increased solar reflectance that contributes to the reduction of the air temperature because of surface heat balance at the urban level. The indirect benefits arise from this ambient cooling of a city or neighbourhood that will in turn decrease the need for air-conditioning.

Taha et al. (1988) presented studies with DOE simulation to investigate the effect of surface reflectance on building cooling and energy consumption. The results showed that the effect of solar reflectance depends on the outdoor climatic conditions, insulation level, and surface's orientation. For instance, high solar reflectance can decrease the annual energy use in cooling dominated climate but vice versa if heating is dominant. In addition to the effects at building scale, this study also suggested that extensive use of urban surfaces with high solar reflectance could lower urban ambient temperatures, which in turn reduces cooling demand. That is to say, building envelope with high solar reflectance is not only for self benefits but also advantageous to surrounding buildings, and even the whole region.

Bansal, Garg and Kothari (1992), on the other hand, have conducted scale model measurements to study the effect of envelope colour (reflectance) on thermal performance of buildings. The results demonstrated that envelope colour has appreciable effect on the thermal behaviour of buildings. According to these results, a white painted test cell (high solar reflectance) was 7°C cooler than the corresponding black painted cell (low solar reflectance) when they were both exposed to strong solar radiation without the provision for any ventilation.

A study presented by Cheng, Ng and Givoni (2003) concluded that cooling load in buildings with black envelope can be more than twice of that with white envelope; additionally, the effect of light coloured surfaces is most appreciable in uninsulated light mass envelope. According to the authors, in Hong Kong (temperate climate year round) most residential buildings are enveloped in uninsulated thin concrete walls only; consequently, make them the ideal candidates for envelope colour applications. In summary, it is widely recognised that a reflective roof surface in place of a dark one can be of great benefit in hot and sunny climates, increasing human comfort and/or reducing the cooling load (SUEHRCKE; PETERSON; SELBY, 2008).

Roof surfaces are responsible for significant portion of the total solar radiation absorbed by a building. Suehrcke, Peterson and Selby (2008) emphasizes that daytime heat flow from a sun-exposed roof surface is essentially only in downward direction and the downward heat flow generally is undesired, as it tends to overheat the building or put extra load on an air-conditioning system. In particular, use of light-coloured roofing materials has been shown qualitatively to have the potential for reducing solar heat gain and hence air-conditioning cooling loads (TAHA et al, 1988).

The use of reflective materials on the building envelope is one of the most efficient ways to reduce these effects. As a matter of fact, the market of reflective materials consists mainly of white or light coloured materials currently commercially available for rooftops having high solar reflectance values ranging from 0.4 to 0.85 (BERDHAL & BRETZ, 1997; AKBARI, POMERANTZ & TAHA, 2001; DOULOS, SANTAMOURIS & LIVADA, 2004; SYNNEFA, SANTAMOURIS & LIVADA, 2006). According to Synnefa, Santamouris and Akbari (2007), for peak solar conditions (about 1000 W/m^2) for an insulated surface and under a low wind condition, the temperature of a black surface with solar reflectance of 0.05 is about 50°C higher than ambient air temperature. For a white surface with solar reflectance of 0.8, the temperature rise is about 10°C. Surface temperature measurements demonstrated that a cool coating can reduce the concrete tile’s surface temperature by 7.5°C and it can be 15°C cooler than a silver grey coating.

On the other hand, it is growing the need for coloured products because in several cases the aesthetics of darker colours is preferred. Some of these reflective materials, classified as “cool” materials, have been developed aiming to increase their solar radiation reflection and to present high infrared emissivity. Among them, cool paints have being very efficient to reduce the solar heat gains in buildings, mainly for roofs. Generally speaking, “cool roofs” are highly reflective and emissive. In other words, they reflect solar radiation and reradiate absorbed heat as light energy back to the atmosphere, rather than transferring absorbed heat to the building below (VAN TIJEN; COHEN, 2008).

In the last few years, the international market of cool roofs include the use of pigments with reflective properties, also called “cool” pigments, which are non-conventional inorganic pigments for producing energy-efficient coloured products. These pigments are mainly applied in shingle and concrete tiles, and to produce “cool” paints. This special group of non-conventional pigments is known for its highly visible opacity and high reflectance in NIR radiation (UEMOTO; SATO; JOHN, 2010). According to Synnefa, Santamouris and Apostolakis (2007), the maximum difference between the solar reflectance of a cool and conventional colour matched coating was found to be 0.22 with a corresponding surface temperature difference of 10.2°C.

In Brazil, the cool paint market is incipient. Several paint manufacturers commercialize white paints with ceramic micro-spheres, which present high visible reflectance but not exactly high near-infrared reflectance. Nowadays, only one Brazilian paint industry has developed this special roof paint intending to increase its solar reflectance, which is currently commercially available for rooftops. However, this manufacturer does not publish data referred to the reflectance or absorptance of their products.

Uemoto, Sato and John (2010) present results of a study in which the thermal performance of cool coloured acrylic paints containing infrared reflective pigments in comparison to conventional coloured acrylic paints of similar colour were investigated. These paints were formulated and supplied by a Brazilian industrial partner, but in fact these paints were not commercially available. The results demonstrated that cool coloured paint formulations produced significantly higher NIR reflectance than conventional paints of similar colours, and that the surface temperatures were more than 10°C lower than those of conventional paints when exposed to infrared radiation. The study showed that cool paints enhance thermal comfort inside buildings, which can reduce air conditioning costs.

In the same way, the purpose of this study is to report the measured optical properties and the thermal performance of reflective and "cool" paints produced in Brazil for roof paint that are commercially available, compared to conventional paints with similar colour. The spectral reflectances of painted samples were measured using a spectrophotometer and the solar reflectance of the samples was calculated using a standard solar spectrum. In order to indicate the impact on the thermal comfort in no-conditioned buildings for a cooling dominated Brazilian city characterised by a tropical climate, computer simulations were performed using the EnergyPlus simulation program, according to reflectance data obtained with the spectrophotometer and the comfortable temperature intervals according to ASHRAE 55-2004 (ASHRAE, 2004) for natural ventilated buildings.

2. Experimental measurements:

2.1 Samples

This study presents experimental results for 11 coatings commercially available in Brazil. Four samples were produced with white reflective paints formulated with acrylic paint filled with ceramic microspheres, which were compared to one sample produced with standard white acrylic paint. Additionally, it was investigated the spectral and thermal performance of three cool coatings, which were compared with standard coatings with similar colour.

In order to obtain results closer to real surfaces, the samples were prepared with ceramic tablets (35 x 35 mm), with a smooth surface to avoid the roughness effect on the reflectance results. The tablets were painted with three coats of paint with the colour to be analysed, with a minimal interval of two hours between coats, in accordance with the manufacturers' instructions. The samples were carefully painted to obtain homogeneous and uniform surfaces.

2.2 Laboratory measurements

In this work, several laboratory measurements were performed through optical analyses using a double-beam spectrophotometer (Varian CARY 5G), fitted with a 150mm diameter integrating sphere that collects both specular and diffuse radiation, according to the ASTM E903-96 standard (ASTM, 1996). This type of analysis allows measuring the spectral characteristic of samples over the total solar spectrum. Therefore, it is possible to compare the spectral performance of different surfaces exposed to the Sun for the ultraviolet, visible, near-infrared or the total solar spectrum.

The reflectance was determined at wavelength intervals of 1 nm, from 300 to 2500 nm, which is the solar spectrum range with the highest concentration of solar energy according to the ASTM G173-03 (ASTM, 2003). This region was divided into three parts: ultraviolet (300 to 380 nm), visible (380 to 780 nm), and near-infrared (780 to 2500 nm). Actually, analyses by spectrum ranges are not commonly studied by the specialized literature, which only presents data referring to the visible range. Many authors consider that visible reflectance (or absorptance) repeats for the entire solar spectrum. However, some studies demonstrated that opaque surfaces absorb differently for the three solar spectrum ranges (Berdhal and Bretz, 1997; Touloukian, De Witt and Hernicz, 1972; Dornelles and Roriz, 2006). Therefore, reflectance data only for the visible range can cause mistakes because they do not effectively represent how much solar heat a surface reflects.

Spectral reflectance data were used to calculate the solar reflectance of each sample. The calculation was carried out by weighted-averaging, using a standard solar spectrum as the weighting function to compute the overall fraction of solar energy reflected under typical atmospheric conditions. The spectrum employed is that provided by The American Society for Testing and Materials (ASTM G173-03, 2003), as showed in Figure 1.

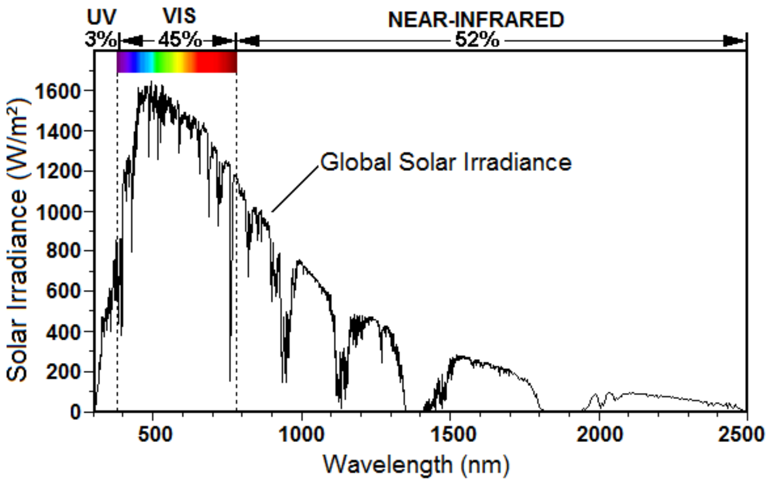

Figure 1: Standard solar spectrum.

3. Results and discussion

The samples spectral reflectance curves are presented in Figures 2 and 3. Average reflectances for each solar spectrum range were obtained to understand the surfaces spectral behaviour in different wavelengths (Table 1), which were already weighted-averaging using the standard solar spectrum.

It can be observed that the conventional white coating presented higher solar reflectance (89.8%) when compared to the cool white paints. As a matter of fact, all the white samples presented high solar reflectance, that is to say, all of these samples are efficient reflective paints (Figure 2). Nevertheless, it would be not necessary to invest in these cool white paints if the conventional one achieves higher solar reflectance, once conventional coatings are usually cheaper than cool coatings.

The cool yellow coating shows similar reflectance to the conventional yellow paint in the visible range, and its reflectance is increased in the near-infrared range for the cool sample, despite that they presented a modest difference in the solar reflectance. On the other hand, samples with brown and red-brown cool coatings presented very similar spectral reflectances when compared to the conventional brown and red-brown paints (Figure 3). In consequence, these cool paints are not enough reflective to classify them as cool coatings.

Table 1: Average spectral reflectances of investigated samples.

Sample		Reflectance (%)			
		UV	VIS	NIR	TOTAL
1	Conventional White	8.3	92.4	91.0	89.8
2	Cool White A	4.9	85.5	83.0	82.5
3	Cool White B	4.8	86.2	81.1	82.1
4	Cool White C	4.2	83.2	76.4	78.3
5	Cool White D	6.2	87.3	85.8	84.8
6	Conventional yellow	5.5	67.7	69.2	67.0
7	Cool yellow	5.3	69.2	77.2	71.4
8	Conventional Brown	3.9	23.3	46.6	33.4
9	Cool Brown	4.0	23.8	47.8	34.2
10	Conventional Red-brown	3.4	17.1	38.2	26.3
11	Cool red-brown	4.3	17.0	37.6	26.0

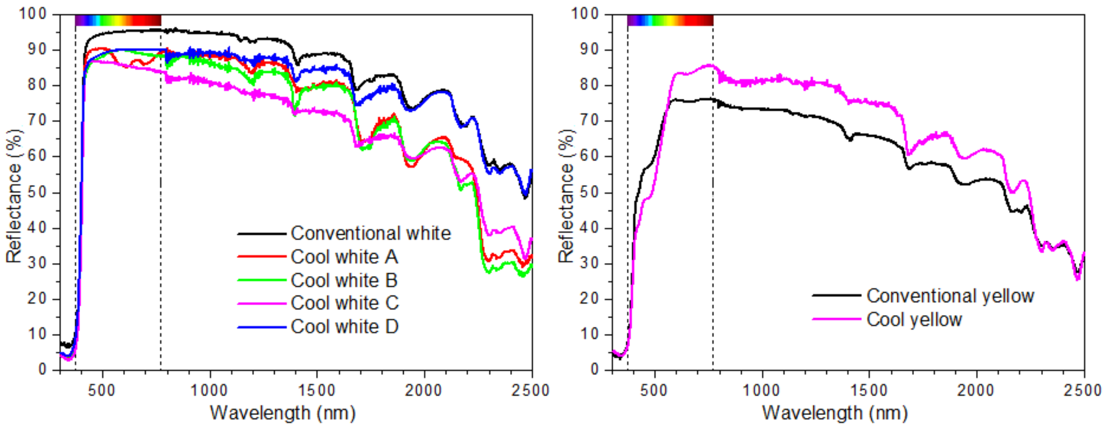

Figure 2: Spectral reflectances of conventional and cool white and yellow samples.

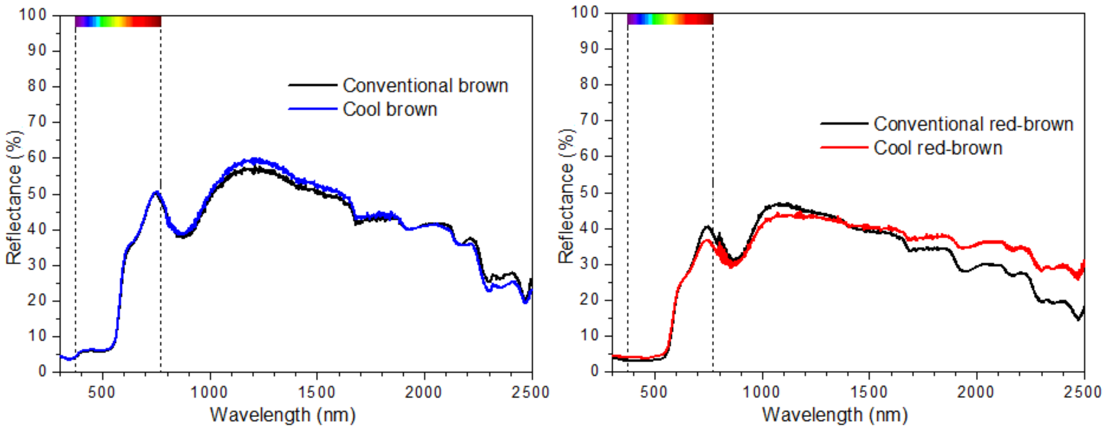

Figure 3: Spectral reflectances of conventional and cool brown and red-brown samples.

4. Simulation:
In order to estimate the effect of the use of cool white and cool coloured materials on the thermal comfort in no-conditioned buildings located in the city of Belem, Brazil, simulations were performed using the EnergyPlus simulation software, according to reflectance data obtained with the spectrophotometer.

Table 2 presents the latitude, longitude and altitude of the selected city, with predominance of tropical climate. The temperatures for the summer design day (December) are presented in Table 3.

Table 2: Latitude, longitude and altitude of Belem, north of Brazil.

City	Latitude (°)	Longitude (°)	Altitude (m)
Belem	1.38 South	48.48 West	10

Table 3: Dry-bulb temperature for the summer design day (December) of Belem.

Hour (h)	Temperature (°C)	Hour (h)	Temperature (°C)
1	23.36	**13**	31.28
2	22.83	**14**	31.9
3	22.52	**15**	31.9
4	22.21	**16**	31.28
5	22.11	**17**	30.13
6	22.00	**18**	29.09
7	22.32	**19**	28.05
8	23.36	**20**	27.00
9	24.81	**21**	26.17
10	26.58	**22**	25.34
11	28.36	**23**	24.5
12	30.03	**24**	23.87

Energyplus Energy Simulation Software was used for the simulations. The meteorological data were taken from the weather database of the US Department of Energy, which presents weather data for more than 2100 locations (http://apps1.eere.energy.gov/buildings/energyplus/). The base case building used in the simulation is a single story, flat roof house, as showed in Figure 4. This building is a real example of residential buildings that are currently being built in Brazil, mainly for low-cost houses. Its height is assumed to be 2.7 m and each wall and ceiling is made of 10 cm of concrete. The solar absorptance of walls was assumed to be 0.5 and window area is 1.44 m² each one, with half of this area with clear 3mm glass. Bathroom has one window with 0.36 m² of clear 3mm glass. The roof is covered with a 6mm fibre cement tile, whose solar reflectance was considered according to the spectrophotometric measurements.

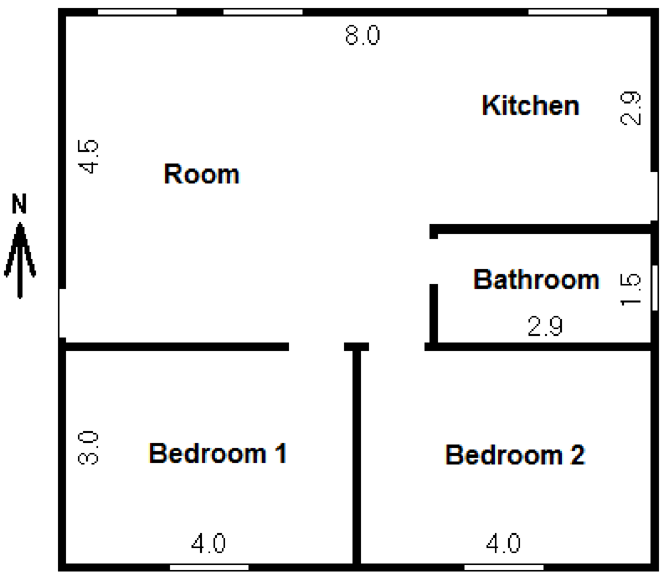

Figure 4: Base case building used in the simulation.

Infiltration and ventilation rates were set as 1/hour, according to the Brazilian standard NBR 15575 (ABNT, 2008). Regarding internal gains, simulations considered thermal loads from the rooms' occupancy (people, lighting and equipments), according to a typical Brazilian family for which this kind of buildings are designed for (low-cost houses), as following (Tables 4, 5 and 6):

Table 4: Number of occupants in sedentary activities: two adults (100W/person) and two kids (60 W/person).

Hour	Room	Kitchen	Bedroom 1	Bedroom 2	Hour	Room	Kitchen	Bedroom 1	Bedroom 2
1	0	0	2	2	**13**	1	1	0	0
2	0	0	2	2	**14**	0	1	0	0
3	0	0	2	2	**15**	1	1	0	0
4	0	0	2	2	**16**	2	1	0	0
5	0	0	2	2	**17**	3	1	0	0
6	0	1	1	2	**18**	4	0	0	0
7	0	1	1	1	**19**	4	0	0	0
8	0	1	0	0	**20**	4	0	0	0
9	0	1	0	0	**21**	4	0	0	0
10	0	1	0	0	**22**	4	0	0	0
11	1	1	0	0	**23**	3	0	0	1
12	2	1	0	0	**24**	2	0	1	1

Table 5: Room equipments (lighting: 100W; TV: 50W).

Hour	Lighting	TV	Hour	Lighting	TV
1	-	-	**13**	-	-
2	-	-	**14**	-	-
3	-	-	**15**	-	X
4	-	-	**16**	-	X
5	-	-	**17**	-	X
6	-	-	**18**	X	X
7	-	-	**19**	X	X
8	-	-	**20**	X	X
9	-	-	**21**	X	X
10	-	-	**22**	X	X
11	-	-	**23**	X	X
12	-	-	**24**	X	X

Table 6: Kitchen equipments (lighting: 100W; refrigerator: 90W; stove: 60W).

Hour	Lighting	Refrigerator	Stove	Hour	Lighting	Refrigerator	Stove
1	-	X	-	**13**	-	X	-
2	-	X	-	**14**	-	X	-
3	-	X	-	**15**	-	X	-
4	-	X	-	**16**	-	X	-
5	-	X	-	**17**	X	X	-
6	X	X	X	**18**	X	X	X
7	X	X	X	**19**	-	X	X
8	-	X	-	**20**	-	X	X
9	-	X	-	**21**	-	X	-
10	-	X	X	**22**	-	X	-
11	-	X	X	**23**	-	X	-
12	-	X	X	**24**	-	X	-

This building type may not necessarily be representative of typical houses in tropical climates. However, the purpose of this study is to report the influence of roof reflectance on the thermal comfort conditions from changing the roof’s solar reflectance comparatively. In addition to the solar reflectance obtained in this study for the 11 different samples (cool and conventional coatings), it was included in the simulation part reflectances of seven samples presented by Uemoto, Sato and John (2010). These samples include three cool paints and their equivalent conventional ones produced in Brazil, as well as the spectral reflectance of fibre cement specimen, widely used for roofing in developing, tropical countries. On account of the fact that the authors only presented reflectance curves from the spectrophotometer measurements and average reflectance of the analysed samples, it was necessary to estimate the spectral reflectance curves in order to calculate the solar reflectance of each sample, by weighted-averaging using the standard solar spectrum (ASTM G173-03, 2003). In this case, the samples spectral reflectance curves were obtained through digital reading aided by computer software. The infrared emittance for all samples was considered to be 0.9.

In order to evaluate the thermal comfort conditions for each situation, it was adopted comfortable temperature intervals according to ASHRAE 55-2004 for natural ventilated buildings (Equation 1, ASHRAE 2004). The main advantage of this standard is its adaptative character, which means that this standard recognizes that occupants used to living in warm climates prefer higher temperatures than those preferred by occupants living in cold climates, and vice versa.

$$Tc = 17.9 + 0.31 * To \qquad \text{[Eq. 01]}$$

Where:
Tc: Comfort temperature (ºC).
To: Arithmetic average of the mean daily minimum and mean daily maximum outdoor (dry bulb) temperatures for the month in question (ºC), where equation 1 is valid for **To** between 10.0 and 33.5 ºC.

Around the comfort temperature, ASHRAE indicates a comfortable interval of temperatures whose superior limit is determined by Equation 2 and the inferior limit by Equation 3.

$$\text{Superior limit} = Tc + \text{tolerance} \qquad \text{[Eq. 02]}$$

$$\text{Inferior limit} = Tc - \text{tolerance} \qquad \text{[Eq. 03]}$$

Where:
Tc: Comfort temperature (ºC);
Tolerance: in this work it was adopted a tolerance of 2.4^{o}C, which according to ASHRAE 55-2004 satisfies 90% of the occupants. In order to attend 80% of the occupants, the ASHRAE 55-2004 standard indicates a tolerance of 3.4 ^{o}C.

The thermal discomfort in the simulated building submitted to different roof reflectances was quantified in degrees-hour (^{o}Ch) of heat or cold conditions. Each degree-hour corresponds to the discomfort caused by the air temperature (dry-bulb) when this is lower than the inferior limit (cold) or when it is higher than the superior limit (heat), in 1^{o}C during 1 hour. Diary, monthly or annual levels of discomfort are the sum of these levels occurred along the respective period of time (Figure 5).

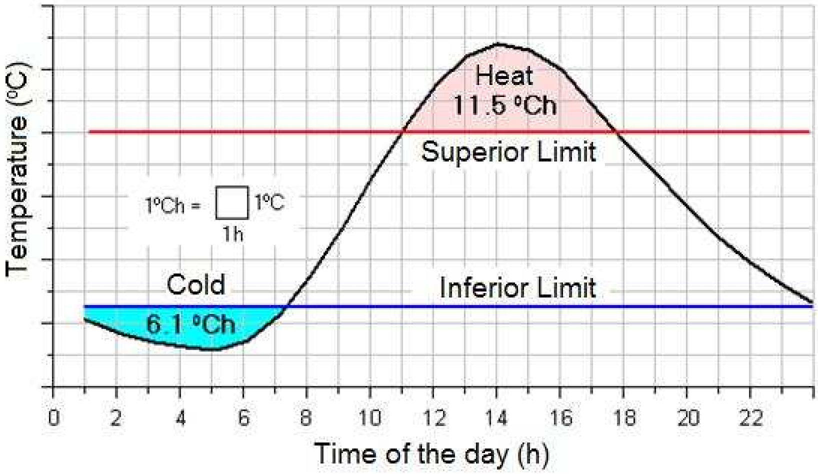

Figure 5: Example of the determination of degrees-hour of discomfort.

As a result, it was found the following comfortable limits for indoor temperatures considered in the building simulation, from equations 1, 2 and 3 (Table 7):

Table 7: Comfortable limits for indoor air temperatures considered in the simulation.

To	Tc	Inferior Limit	Superior Limit
26.29	26.05	23.55	28.55

According to these limits, the following degrees-hour per day (^{o}Ch/day) of discomfort by heat was found for the building with 18 different solar reflectances (Table 8):

Table 8: Degrees-hour/day of discomfort by heat for a summer design day.

	Sample	Solar Reflectance (%)	Visible Absorptance (%)	Solar Absorptance (%)	Heat Discomfort (^{o}Ch/Day)
1	Conventional White	89.8	7.6	10.2	**0.0**
2	Cool White A	82.5	14.5	17.5	**0.0**
3	Cool White B	82.1	13.8	17.9	**0.0**
4	Cool White C	78.3	16.8	21.7	**0.6**
5	Cool White D	84.8	12.7	15.2	**0.0**
6	Conventional yellow	67.0	32.3	33.0	**3.7**
7	Cool yellow	71.4	30.8	28.6	**2.2**
8	Conventional Brown	33.4	76.7	66.6	**14.0**
9	Cool Brown	34.2	76.2	65.8	**13.8**
10	Conventional Red-brown	26.3	82.9	73.7	**16.4**
11	Cool red-brown	26.0	83.0	74.0	**16.5**
12	*Fibre cement	48.0	52.3	52.0	**9.9**
13	*Cool White	84.4	12.6	15.6	**0.0**
14	*Conventional White	81.5	11.4	18.5	**0.1**
15	*Cool Brown	43.3	74.1	56.7	**10.9**
16	*Conventional Brown	29.1	75.6	70.9	**15.5**
17	*Cool yellow	62.7	55.2	37.3	**5.0**
18	*Conventional yellow	52.7	56.5	47.3	**8.3**

** Samples evaluated by Uemoto, Sato and John (2010), and included in this work for simulation purposes.*

Figure 6 correlates the samples solar reflectance and the corresponding degrees-hour of discomfort by heat per day. It can be noticed that as higher is the solar reflectance of a roof surface, the lower is the discomfort by heat for buildings located in tropical climates as in the city of Belem, north of Brazil.

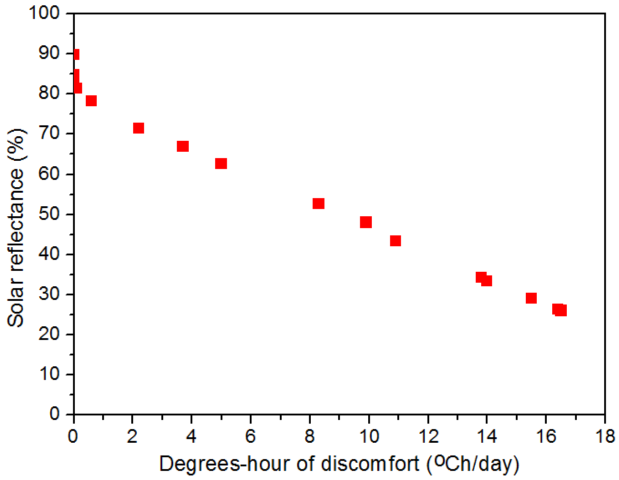

Figure 6: Correlations between solar reflectance and degrees-hour of discomfort by heat.

The results showed that the use of conventional or cool white coatings for cooling roof surfaces are efficient in reducing the discomfort by heat inside buildings located in tropical climates. According to these results, a building with fibre cement roofing (sample nº 12) with solar reflectance of 48% presents 9.9°Ch/day of discomfort by heat for the summer design day for Belem. If this roof was painted with a conventional or cool white coating (solar reflectance higher than 80%), the discomfort by heat could be eliminated from this building, offering comfort conditions for the occupants.

It can be noticed that darkest coatings (samples 8, 9, 10, 11, 15 and 16) presented lower solar reflectance, which implied in higher indoor discomfort by heat for summer conditions. Cool coatings with brown and red-brown colours investigated in this study presented miserable increase in the solar reflectance when compared to the correspondent conventional coatings. For cool coatings (*) evaluated by Uemoto, Sato and John (2010) this increase was more significant, that is to say, they produced higher difference in applying cool coatings on rooftop than the correspondent conventional ones. These cool paints (samples 13, 15 and 17), besides not being commercially available in Brazil are more energy efficient than the cool paints investigated in this research (samples 2-5, 7, 9 and 11), because they reflect more solar energy than these ones.

5. Conclusion:

This study demonstrated the effect of using reflective materials on improving the thermal comfort conditions for buildings located in tropical climates by showing that there is a correlation between the solar reflectance and the degrees-hour of discomfort by heat that building's occupants are submitted when roof solar reflectance changes from 0.26 to 0.898. It was found that painting the roof surface with white paint is the most efficient way to reduce thermal discomfort conditions by heat for a single story building located in Belem, north of Brazil. The results of this study also emphasize that the most efficient cool paints are those with higher spectral near-infrared reflectance than standard coatings, which in consequence increases the coating`s solar reflectance.

Furthermore, a simulation study was carried out aiming to assess the impact of using cool coatings on roofs on the thermal comfort conditions in residential buildings located in tropical climates. It was found that an increase in roof solar reflectance by 0.638 resulting from the application of a white coating reduces discomfort by heat from 16.5^{o}Ch/day to 0.0^{o}Ch/day.

In summary, the use of reflective or cool paints on roof surfaces is a passive solution for buildings located in tropical and hot climates that can contribute to increasing thermal comfort by lowering indoor air temperatures and, consequently, reducing energy demand for cooling. The results of this study aimed to show the importance of spectral reflectance measurements of cool paints commercially available in Brazil, and to motivate the use and development of these materials to minimize the harmful effects caused by the urban heat islands, the increasing energy consumption with cooling systems and the thermal discomfort in buildings no-conditioned, mainly for hot and tropical climates.

6. References:

AKBARI, H.; POMERANTZ, M.; TAHA, H. (2001), Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy, Vol.70, pp.295-310.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (1996), E903-96: standard test method for solar absorptance, reflectance, and transmittance of materials using integrating spheres. ASTM International.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (2003), G173-03: standard tables for reference solar spectral irradiances - direct normal and hemispherical on 37° tilted surface. ASTM International.

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS (2004), 55-2004: thermal environmental conditions for human occupancy. ASHRAE, Atlanta.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2008), NBR 15575: residential buildings up to five storied - Performance. ABNT, Rio de Janeiro.

BANSAL, N. K.; GARG, S. N.; KOTHARI, S. (1992), Effect of exterior surface colour on the thermal performance of buildings, Building and Environment, Vol. 27, No. 1, pp. 31-37.

BERDHAL, P.; BRETZ, S. E. (1997), Preliminary survey of the solar reflectance of cool roofing materials. Energy and Buildings, Vol.25, pp. 149-158.

CHENG, V.; NG, E.; GIVONI, B. (2003), Sensitivity of envelope colour: effect of thermal mass, windows, and natural ventilation on high-rise buildings in hot humid Hong Kong. Proceedings of the 20th Conference on Passive and Low Energy Architecture, Santiago, Chile, 9-12 November 2003.

DORNELLES, K. A.; RORIZ, M. (2004), Thermal inertia, comfort and energy consumption in buildings: a case study in Sao Paulo state - Brazil. *International Journal for Housing and its Applications*, Vol.28, No.2, pp. 153-162.

DORNELLES, K. A.; RORIZ, M. (2006), A method to identify the solar absorptance of opaque surfaces with a low-cost spectrometer. In: Conference on Passive and Low Energy Architecture, 23., 2006, Geneva. Proceedings... Geneva.

DOULOS, L.; SANTAMOURIS, M. LIVADA, I. (2004), Passive cooling of outdoor urban spaces: the role of materials. Solar Energy, Vol.77, pp.231-249.

GIVONI, B. (1998), Climate considerations in building and urban design. Van Nostrand Reinhold, New York.

SUEHRCKE, H.; PETERSON, E. L.; SELBY, N. (2008), Effect of roof solar reflectance on the building heat gain in a hot climate. Energy and Buildings, Vol. 40, pp. 2224-2235.

SYNNEFA, A.; SANTAMOURIS, M.; AKBARI, H. (2007), Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy and Buildings, Vol. 39, pp. 1167–1174.

SYNNEFA, A.; SANTAMOURIS, M.; APOSTOLAKIS, K. (2007), On the development, optical properties and thermal performance of cool colored coatings for the urban environment. Solar Energy, Vol. 4, No. 4, pp. 488-497.

SYNNEFA, A.; SANTAMOURIS, M.; LIVADA, I. (2006), A study of the thermal performance and of reflective coatings for the urban environment. Solar Energy, Vol.80, pp.968-981.

TAHA, H.; AKBARI, H.; ROSENFELD, A.; HUANG, J. (1988), Residential cooling loads and the urban heat island – the effects of albedo, Building and Environment, Vol. 23, No. 4, pp. 271-283.

TOULOUKIAN, Y. S.; DE WITT, D. P.; HERNICZ, R. S. (1972), Thermal radiative properties. Coatings, Thermophysical Properties of Matter, Vol. 9, IFI/Plenum. New York.

UEMOTO, K. L.; SATO, N. M. N.; JOHN, V. M. (2010), Estimating thermal performance of cool colored paints. Energy and Buildings, Vol. 42, pp. 17-22.

VAN TIJEN, M.; COHEN, R. (2008), Features and benefits of cool roofs: the cool roof rating council program. Journal of Green Building, Vol.3, No.2, pp. 13-19.

Acknowledgements:
The authors wish to thank the Interdisciplinary Research on Ceramics Laboratory (LIEC) at the Federal University of Sao Carlos, and the Institute of Chemistry at Sao Carlos of the University of Sao Paulo (IQSC-USP) for the spectrophotometric measurements. The State of Sao Paulo Research Foundation (FAPESP), Brazil, sponsors this research.