THERMAL PERFORMANCE OF WHITE SOLAR-REFLECTIVE PAINTS FOR COOL ROOFS AND THE INFLUENCE ON THE THERMAL COMFORT AND BUILDING ENERGY USE IN HOT CLIMATES

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1. Introduction

Energy and material use are increasing significantly worldwide and buildings in urban areas are responsible for much of this growth in the intensity of energy and material consumption (GOLDEN, 2003). Of the many ways in which buildings impact the environment, the emission of greenhouse gases (GHG) and the creation of microclimates within urban areas are among the most prominent (UNEP, 2007). Greenhouse gases emissions are directly related to the energy consumed during all the stages of a building's life, including manufacture, transportation, construction, operation and demolition. Over the entire lifetime of a building, the operational energy is the most significant of these (JO et al., 2010).

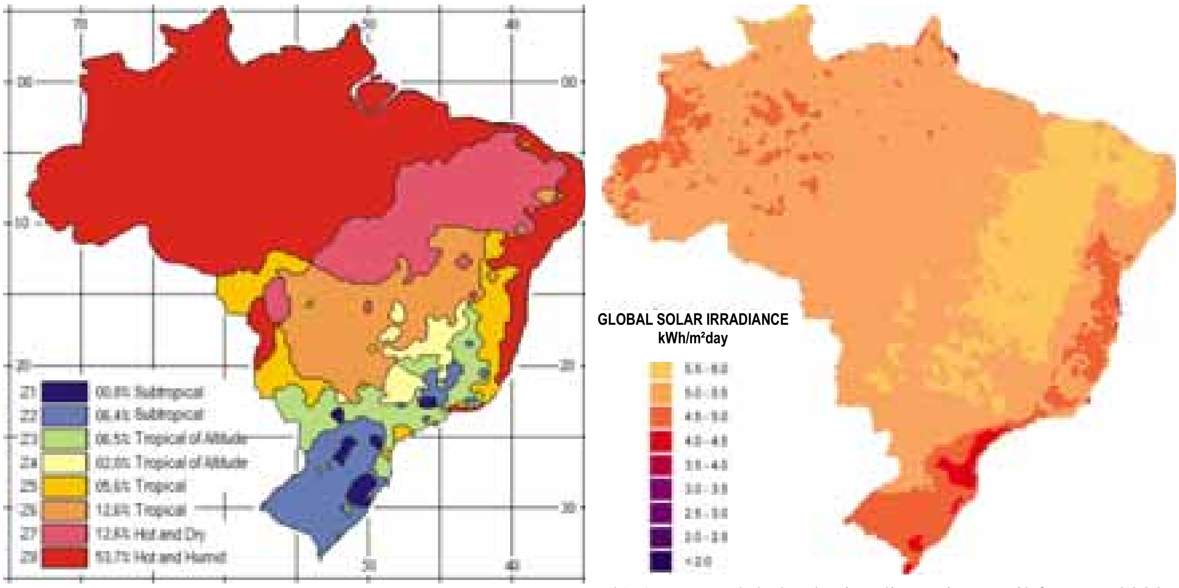
In most countries, residential buildings are responsible for a major part of the energy consumption in the building sector (UNEP, 2007). Studies indicate that buildings in Brazil (commercial, residential and public services) account for 44.7% of the energy use (electricity): the non-residential sector accounts for 22.7% and the residential sector for 22% of the total (BEN, 2007).

The pattern of energy use in buildings is strongly related to the building type and the climate zone where it is located. On account of the fact that urban areas around the world are experiencing rapid population growth and urban sprawl with consequent increase in the impermeable urban surfaces, the more intense solar energy absorption by concrete and paved surfaces causes the surface temperature increase several degrees higher than ambient air temperatures (SYNNEFA et al., 2007). With this increase in the ambient air temperature there is consequent increase in the buildings surface temperatures and the air temperature inside the buildings, causing thermal discomfort for users in no conditioned buildings or higher energy demand for cooling systems.

Improving the thermal properties of the existing building envelope is, in many cases, one of the most logical solutions in order to reduce the building energy consumption. As a consequence, this is also one of the most important strategies in building retrofit. The level of improvement achieved through a renovation of the building envelope often depends on a combination of factors, involving windows, doors, walls and roofs. An unbalanced intervention between different components can lead to unsatisfactory results (UNEP, 2007).

Hot climatic conditions generally prevail in low altitude areas between 15º north and south latitudes. A significant portion of the global population lives in this region, notably countries in North and South America, Africa, India, Indonesia, Malaysia, Thailand and the Philippines. Therefore, it would be quite useful to develop strategies that could be included in designing modern passive houses. Such techniques would be useful in reducing the use of energy-consuming active means on most days of the year, especially when climatic conditions are not extreme. In this region, the path of the sun generally goes through high altitudes during the daytime, subjecting the roofs of dwellings to intense sunlight. Unlike vertical surfaces such as walls, the roof is exposed to the sun throughout the daytime round the year, significantly contributing to building heat gain (JAYASINGHE et al., 2003).

In Brazil, solar radiation is responsible for important portion of the thermal load from buildings. According to the Brazilian standard NBR 15220-3 "Thermal performance in buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses" (ABNT, 2005), in Brazil there is a broad range of climatic differences and for this reason it was divided into eight zones according to their climatic characteristics (Figure 1a). Based upon this division, a set of specific bioclimatic design strategies was indicated in this standard focusing its application during the early design stage. It can be observed from Figure 1a that most of the Brazilian area is dominated by tropical and hot climates (zones Z5, Z6, Z7 and Z8). In these cases, solar radiation levels are sufficiently high that even during the winter buildings do not require active heating (Figure 1b). On the other hand, the summer overheating due to solar radiation negatively affects comfort in the built environment and contributes substantially to the electricity consumption for air conditioning.



(a) Brazilian Bioclimatic Zones (ABNT, 2005)

(b) Average global solar irradiance in Brazil for year 2000. (MARTINS et al, 2005)

Figure 1 – Brazilian Bioclimat Zones (a) and average global solar irradiance in Brazil for the year 2000 (b).

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 heat gains of the building 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.

Roof surfaces are responsible for significant portion of the total solar radiation absorbed by a building. Suehrcke et al. (2008) emphasize 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-colored 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. According to Synnefa et al. (2007), for peak solar conditions (about 1000 W/m²) 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.

In the same way, the purpose of this study is to report the measured optical properties and the thermal performance of white solar-reflective paints filled with ceramic microspheres produced in Brazil for roof paint that are commercially available, compared to one white conventional paint (acrylic). The paint manufacturers usually commercialize white solar-reflective paints with ceramic microspheres as *"thermal insulation materials"* for roofs, because of the inclusion of this component in the paint film. Ceramic microspheres are very tiny, round particles that are distributed throughout the dried paint film (Figure 2). The main benefits of ceramic paints, according to the manufacturers, are: smoother, more continuous paint film that resists cracking; superior stain resistance; reduces dirt accumulation; thermal insulation for the building surface; etc.

Figure 2 – Paint film with ceramic microspheres (Paint Quality Institute, http://www.paintquality.com/) .

In order to analyze the thermal performance of these paints, spectral reflectances of painted samples were measured using a spectrophotometer and the solar reflectance of the samples was calculated using a standard solar spectrum. With the aim to indicate the impact on the thermal comfort in no-conditioned buildings for hot/dry and hot/humid climates in Brazil, computer simulations were performed using the EnergyPlus simulation program, according to the reflectance data obtained with the spectrophotometer and the comfortable temperature intervals indicated by ASHRAE 55-2004 for naturally ventilated buildings (ASHRAE, 2004).

2. Experimental procedure

In this work, it was evaluated the thermal performance of white solar-reflective paints filled with ceramic microspheres (acrylic paint). Seven different paints were selected from a range of products commercially available in Brazil as *"thermal insulation materials"* for roofs and the results were compared to one sample produced with standard white acrylic paint. Besides the white paints, a black paint was included in this work with the purpose of comparative analysis. The solar reflectance of this paint was measured with a spectrophotometer in previous author's research (DORNELLES et al., 2007).

This work was divided into three main procedures:

- Spectral and solar reflectance measurements for white solar-reflective paints, with a double-beam spectrophotometer;
- Surface temperature measurements for samples exposed to the sun;
- Computer simulations and estimate of cooling energy consumption in buildings.

2.1. Spectral and solar reflectance of the coatings

Spectral reflectance measurements were performed for selected paints using the Varian Cary 5G double-beam spectrophotometer, considering both specular and diffuse radiation according to the ASTM E903-96 standard (ASTM, 1996). 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). The samples prepared for this procedure were carefully painted to obtain homogeneous and uniform surfaces.

Spectral reflectance data obtained in this work 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, 2003), as showed in Figure 3.

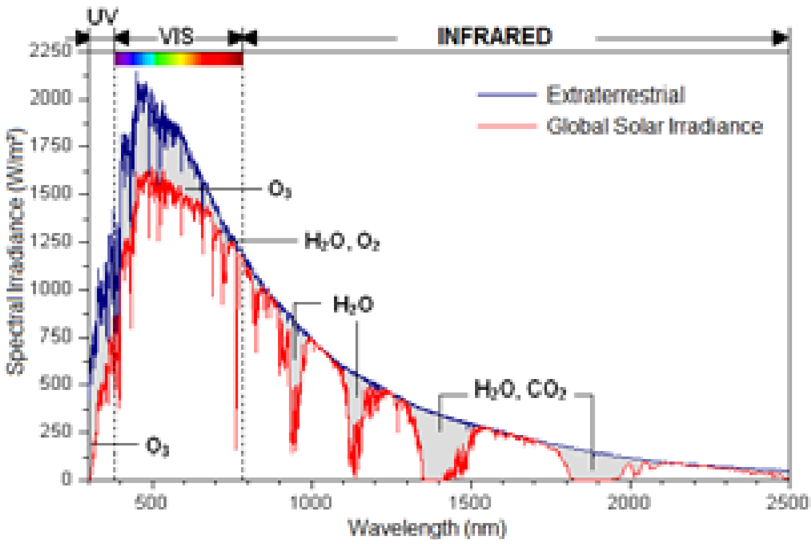


Figure 3 – Standard solar spectrum.

The samples spectral reflectance curves are presented in Figures 4 to 7, and the average reflectances for each solar spectrum range were already weighted-averaging using the standard solar spectrum (Table 1). The white conventional paint is presented as reference in all graphics for comparative purpose, and in Figure 8 reflectance curves for all samples are presented, in order to compare the spectral behavior of the paints.

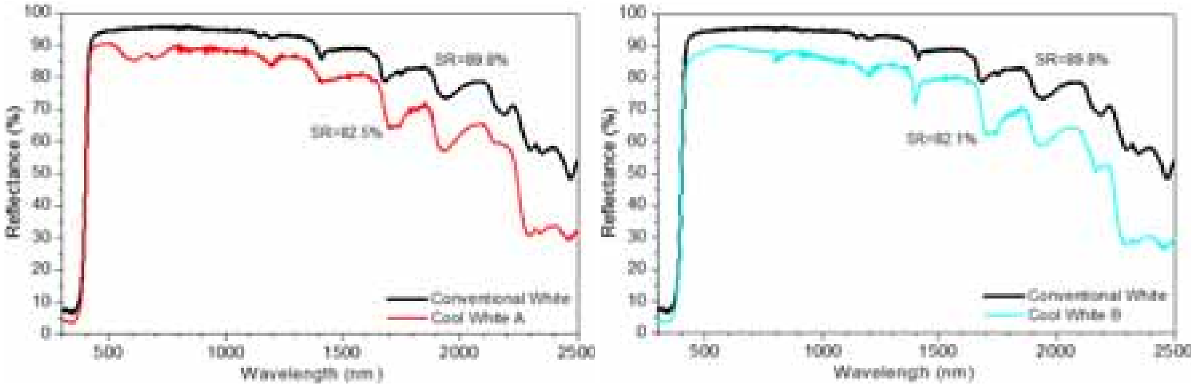


Figure 4 – Spectral reflectance curves for Conventional White, Cool White A, and Cool White B paints.

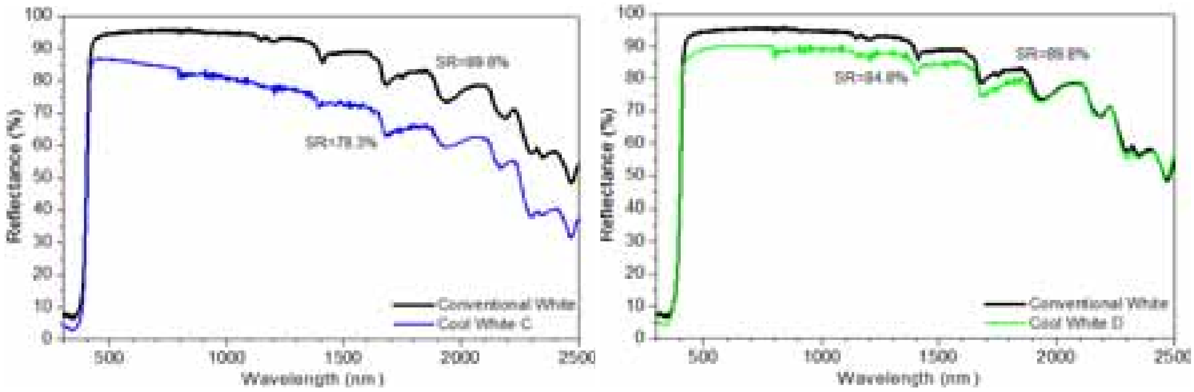


Figure 5 – Spectral reflectance curves for Conventional White, Cool White C, and Cool White D paints.

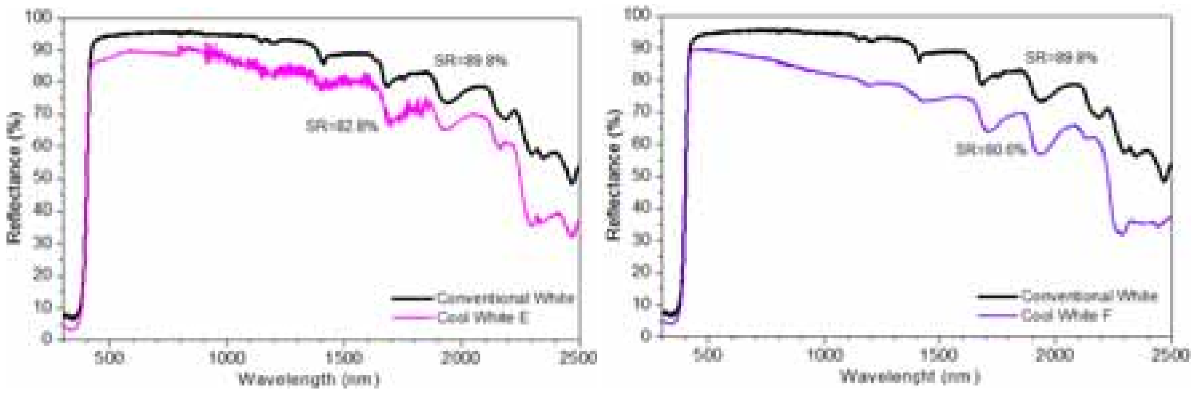


Figure 6 – Spectral reflectance curves for Conventional White, Cool White E, and Cool White F paints.

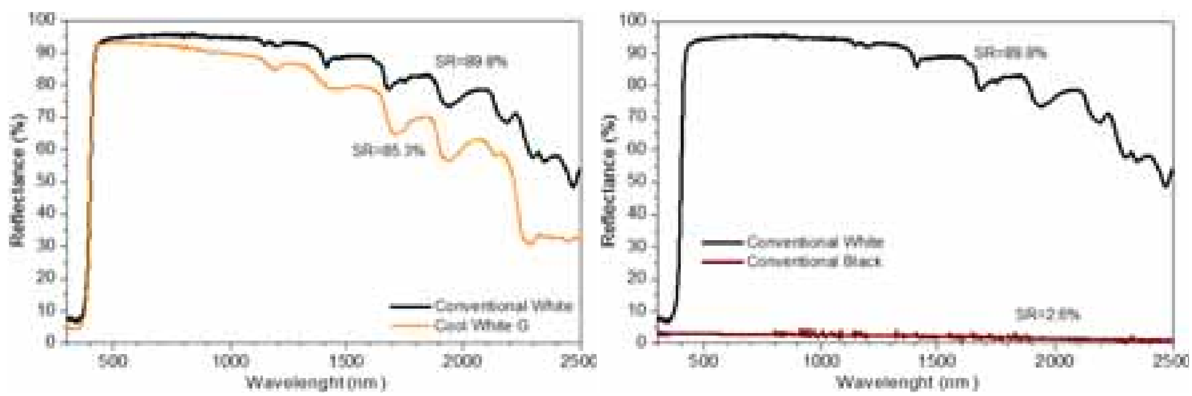


Figure 7 – Spectral reflectance curves for Conventional White, Cool White G, and Conventional Black paints.

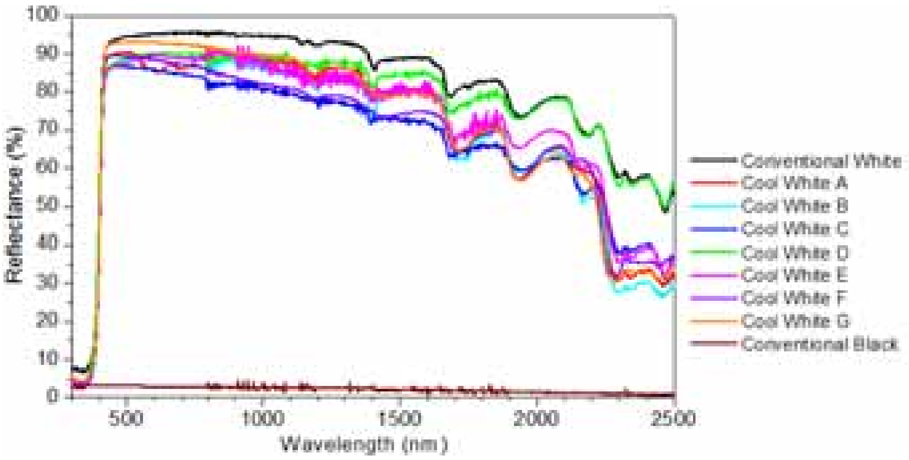


Figure 8 – Spectral reflectance curves for all white samples and conventional black paint.

It can be observed that the conventional white coating (sample 1) presented higher solar reflectance (89.8%) when compared to cool white paints filled with ceramic microspheres. As a matter of fact, all the white samples presented high solar reflectance (higher than 78%), that is to say, all of these samples are efficient reflective paints.

Tab. 1: Weighted-average spectral reflectances, using the standard solar spectrum.

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	Cool White E	4.7	86.1	83.0	82.8
7	Cool White F	5.3	85.9	78.1	80.6
8	Cool White G	5.5	90.0	83.8	85.3
9	Conventional Black	2.9	2.9	2.3	2.6

2.2. Thermal performance of the coatings

In order to analyse the thermal performance of the coatings, surface temperature measurements were performed for all samples exposed to the sun. An electronic device for the data acquisition was adopted consisting of temperature sensors model DS18B20 manufactured by *Maxim Integrated Products Company*, whose accuracy is ± 0.5°C according to the manufacturer (Figure 9).

(a) Temperature sensor.

(b) Measured data acquisition device.

Figure 9 – Temperature sensor (a) and electronic device for surface temperature measurements (b).

The temperature sensors were taped on the samples base with aluminium foil tape and the samples were positioned on a platform insulated from below with expanded polystyrene in order to eliminate the heat transfer effects between the platform and the samples (Figure 10). Additionally, the ambient air temperature (DBT) was also measured. The samples were exposed to solar radiation on the platform and the surface temperature measurements were performed during 2h30 at 1 minute intervals on 5th October 2010, from 12h30 to 15h, which is the period with higher solar irradiance during a sunny day with high air temperatures.

(a) Sample with temperature sensor.

(b) Platform with tested samples.

Figure 10 – Sample with temperature sensor (a) and tested samples placed on the insulated platform (b).

In Figure 11 the surface temperatures measured for all the samples exposed to the sun are presented, as well as the ambient air temperature (Dry Bulb Temperature – DBT). It can be observed that temperatures oscillated between 30 °C and 70 °C. The black sample reached the highest surface temperature (67.6 °C) and the conventional white sample the lowest temperatures.

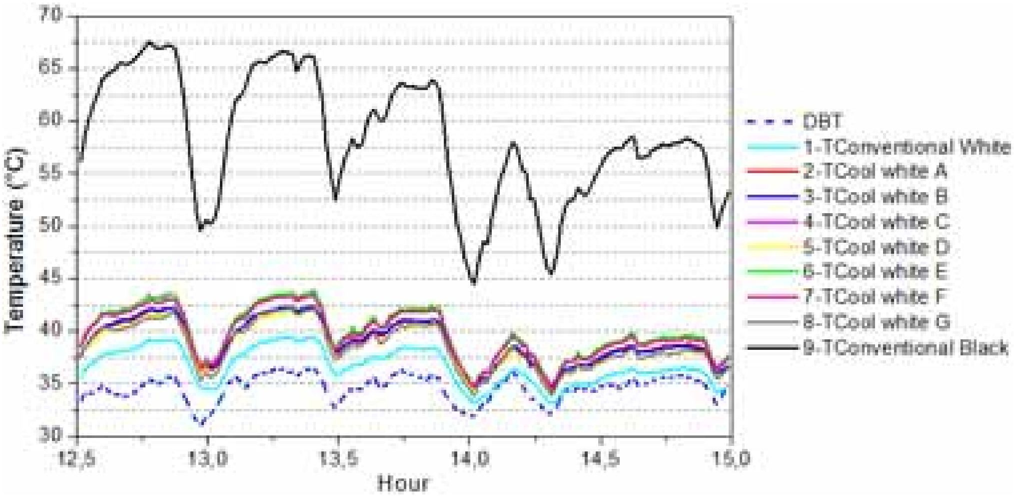


Figure 11 – Samples surface temperatures and ambient air temperature.

The black paint surface temperature curve was excluded from the next graphic (Figure 13) in order to obtain a large-scale graphic with better visualization of the surface temperature variation for white samples. It can be observed that there are maximum variations of 5K among the surface temperatures of the white samples, which indicates that colour is not the only determinant factor of how much solar energy a surface can reflect. Nevertheless, the ceramic microspheres present in the paints composition do not interfere considerably in the surface temperatures reduction, as the paint manufacturers have indicated. Actually, the conventional white acrylic paint without ceramic microspheres presented higher solar reflectance than those which contain this component.

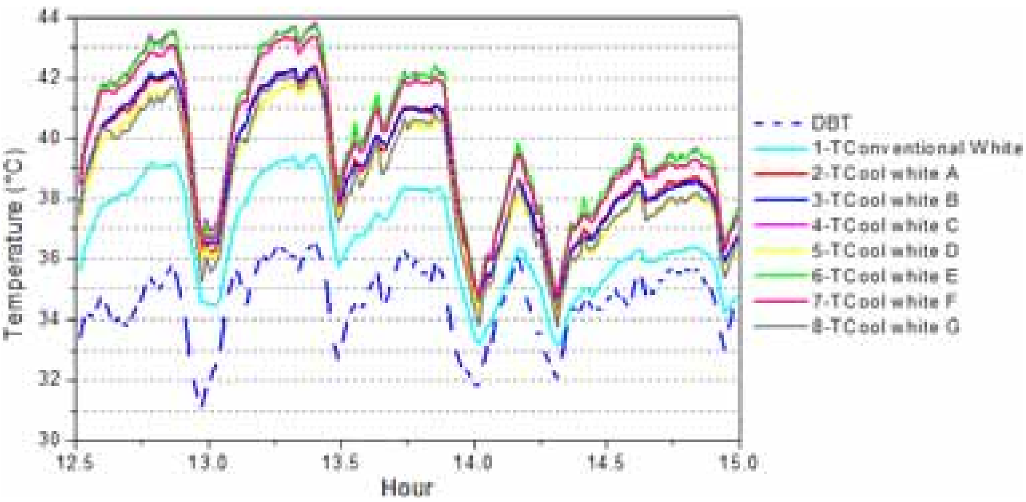


Figure 12 – Surface temperatures of the white samples and ambient air temperature.

In certain moments the graphic presents some decrease in the temperatures and suddenly an increase, which were caused by the presence of some clouds during the measurement, obstructing the direct solar radiation incidence on the samples. However, this event has not damaged the continuity of the measurements during the considered period.

Table 3 presents the maximum and minimum surface and ambient air temperatures measured for each sample. For the white samples with ceramic microspheres small differences can be observed among their surface temperatures, as presented in Figure 12. Nevertheless, the conventional white paint presented the lowest temperatures with regard to the other samples. These results make evident that the presence of ceramic microspheres in the paints composition do not make them thermal insulation materials. The great potential use of these paints in order to reduce surface temperatures for roofs exposed to the sun is due to the high solar reflectance of these paints, as it can be observed comparatively with the data presented in Table 2.

Tab. 2: Maximum and minimum temperatures for samples exposed to the sun and respective solar reflectances.

Sample		Solar reflectance (%)	Temperature [°C]	
			Minimum	Maximum
--	DBT	---	31,14	36,50
1	Conventional White	89,8	**33,09**	39,39
2	Cool White A	82,5	34,30	42,38
3	Cool White B	82,1	34,55	42,28
4	Cool White C	78,3	34,71	43,84
5	Cool White D	84,8	34,07	41,93
6	Cool White E	82,8	34,55	43,75
7	Cool White F	80,6	34,68	43,37
8	Cool White G	85,3	33,78	42,09
9	Conventional Black	2,6	44,48	**67,55**

3. Heat discomfort and cooling energy simulation

3.1. Climates and building description

In order to estimate the effect of using cool roofs on the thermal comfort in buildings located in hot climates, simulations were performed using the EnergyPlus simulation software for a building located in two Brazilian cities with different hot climatic conditions (hot/dry and hot/humid). The city of "Belem" was adopted as representative of hot and humid climate (Zone 8) and the city of "Sao Raimundo Nonato" as representative of hot and dry climate (Zone 7). The city of Belem is located in the state of Para, North of Brazil, at 1.38 °S latitude, 48.48 ºW longitude and altitude of 10 m. The city of Sao Raimundo Nonato is located in the state of Piaui, Northeast of Brazil, at 9.05 °S latitude, 42.75 ºW longitude and altitude of 330 m (Figure 13).

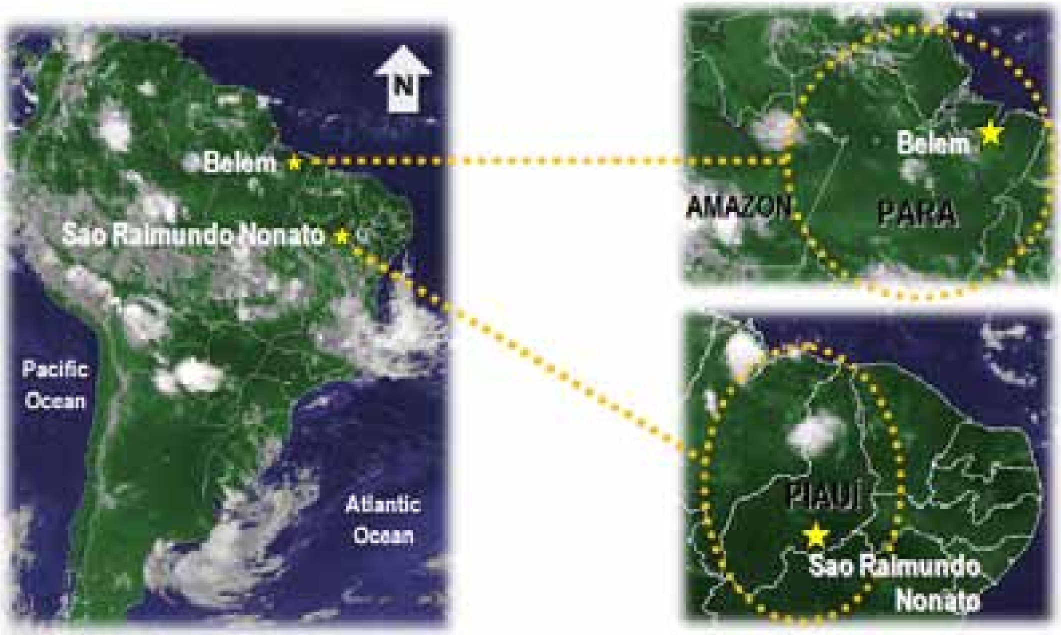
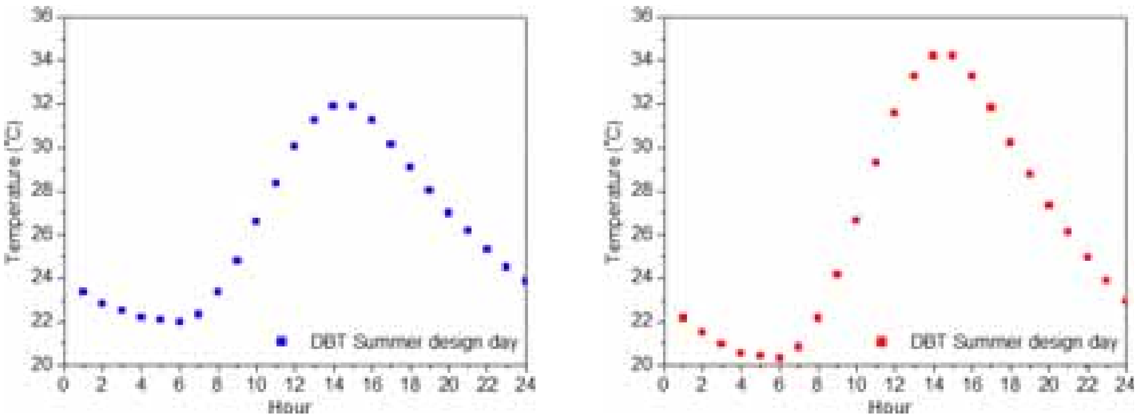


Figure 13 – Location of Belem (hot/humid climate) and Sao Raimundo Nonato (hot/dry climate) in Brazil.

Dry bulb temperatures (DBT) for the summer design day of each city are showed in Figure 14, corresponding to the month of December. Meteorological data were taken from the weather database of the US Department of Energy (http://apps1.eere.energy.gov/buildings/energyplus/), which presents weather data for more than 2100 locations.



(a) Belem, Para. (b) Sao Raimundo Nonato, Piaui.

Figure 14 – Dry bulb temperatures (DBT) in the summer design day for Belem (a) and Sao Raimundo Nonato (b).

The base case building used in the simulation is a single-story flat roof house, as showed in Figure 15. This building is a real example of residential buildings currently built in Brazil, mainly for low-cost houses. Its height is considered as being 2.7 m and each wall and ceiling is made of 10 cm of concrete. The solar absorptance of the walls was considered as being 50% and the window area is 1.44 m² each one, with half of this area with 3 mm clear glass. The bathroom has one window with 0.36 m² of 3 mm clear glass. The roof is covered with a 6 mm fiber-cement tile, whose solar reflectance was considered according to the spectrophotometric measurements for the paints evaluated in this work. The infrared emittance for all samples was considered to be 0.9. Infiltration and ventilation rates were set as 1/hour, according to the Brazilian standard NBR 15575 (ABNT, 2008).

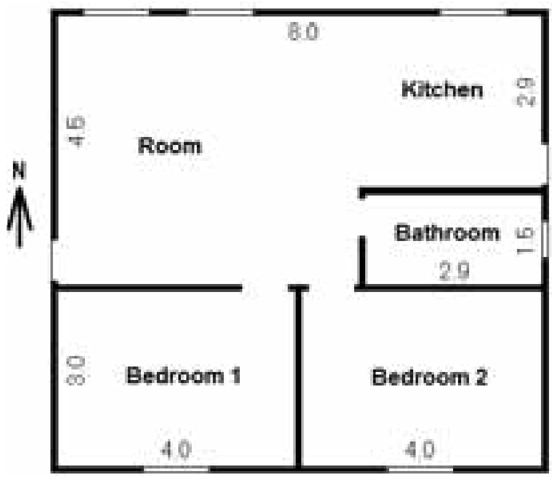


Figure 15 – Base case building used in the simulation.

Regarding internal gains, the simulations considered the thermal loads from the rooms occupancy according to a typical Brazilian household for which these kinds of buildings are designed (low-cost houses, mainly): people (2 adults – 100W/person and 2 children – 60W/person), equipment (TV – 50W, fridge – 90W, stove – 60W) and lighting (100W). This type of building may not necessarily be representative of typical houses in tropical climates. However, the purpose of this study is to report comparatively the influence of roof reflectance on the thermal comfort conditions with the changing of the roof solar reflectance.

3.2. Heat discomfort simulation

In order to evaluate the thermal comfort conditions for each situation, comfortable temperature intervals were adopted according to ASHRAE 55-2004 for naturally ventilated buildings (ASHRAE, 2004), adapted by the authors according to Equation 1:

$Tc = 17.9 + 0.31 * To$ (eq. 1)

Where:

Tc: Comfort temperature (°C)

To: Arithmetic average between the daily minimum average and the daily maximum average of outdoor temperatures (°C), where equation 1 is valid for *To* between 10.0 °C and 33.5 °C.

ASHRAE indicates a comfortable interval of temperatures whose superior limit is determined by Equation 2 and the inferior limit by Equation 3:

Superior limit = Tc + tolerance (eq. 2)

Inferior limit = Tc - tolerance (eq. 3)

Tc: Comfort temperature (°C), and in this work it was adopted a tolerance of 2.4 °C, which according to ASHRAE 55-2004 satisfies 90% of the occupants. In order to attend 80% of the occupants, this standard indicates a tolerance of 3.4 °C.

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 3):

Tab. 3: Comfortable limits for indoor air temperatures considered in the simulation.

City	To (°C)	Tc (°C)	Inferior Limit (°C)	Superior Limit (°C)
Belem	26.29	26.05	23.65	28.45
Sao Raimundo Nonato	26.31	26.06	23.66	28.46

Although there are climatic differences between Belem and Sao Raimundo Nonato, the average temperatures and the comfortable limits are almost the same for both cities.

Thermal discomfort in the building simulated with several roof reflectances was quantified in degrees-hour (°Ch) of heat discomfort, which corresponds to the discomfort caused by the air temperature when it is higher than the superior limit. Daily, monthly or annual levels of discomfort are the sum of the levels occurred along the respective period of time.

3.3. Estimate of cooling energy

Szokolay (1987) presents a simplified method to estimate the cooling energy required to take the accumulated heat out of the room throughout the hours, according to Equation 4:

$Ecool = DH * q$ (eq. 4)

Where:

Ecool: energy for cooling the building room (Wh/day)

DH: accumulated heat throughout the day (Degrees-hour of discomfort, Kh/day)

q: thermal exchange rate by conduction (*qc*) and convection (*qv*), according to Equations 5 (*qc* and *qv* are calculated according to equations 6 and 7):

$q = qc + qv$ (eq. 5)

$$qc = \sum_{i=1}^{n} (A \times U)_i \quad \text{(eq. 6)}$$

$qv = 0.33 * V * N$ (eq. 7)

Where:

qc: thermal exchange rate by conduction (W/K)

A: total area of the envelope (walls, roof, windows, floor - m²)

U: thermal transmittance (W/m²K)

n: number of external sealing that are part of the building envelope qv: thermal exchange rate by convection (W/K)

N: ventilation rate (volumes/h)

V: room volume (m³).

In this way, from the heat discomfort amount estimated according to the different roof solar reflectances, it can be determined in which situation less energy is needed to restore the comfort inside the building.

3.4 Heat discomfort and cooling energy simulation results

Table 4 presents the degrees-hour per day (°Ch/day) of heat discomfort for the building simulated considering nine (9) different solar reflectances for the climates of Belem (Hot/Humid) and Sao Raimundo Nonato (Hot/Dry). The respective estimated cooling energies are also presented in order to restore comfort conditions inside the building (Figure 16). It can be noticed that the higher the solar reflectance of a roof surface is, the lower is the heat discomfort and the cooling energy need for buildings located in hot/humid and hot/dry climates in Brazil.

Solar reflectance data for a fiber-cement roof tile were included in the simulation study for comparative purpose. This data was obtained by Uemoto et al. (2010) for a new fiber-cement tile with light-grey color through spectrophotometric measurements.

Tab. 4: Degrees-hour/day of heat discomfort and cooling energy estimated for Belem (hot humid climate) and Sao Raimundo Nonato (hot dry climate) for the summer design day.

Sample	REFLECTANCE (%)		HEAT DISCOMFORT (°Ch/day)		COOLING ENERGY (Wh/day)	
	VISIBLE	SOLAR	Belem (Hot/humid)	Sao Raimundo Nonato (Hot/Dry)	Belem (Hot/humid)	Sao Raimundo Nonato (Hot/dry)
1 Conventional White	92.4	89.8	0.0	0.0	0.00	0.00
2 Cool White A	85.5	82.5	0.0	0.5	0.00	404.97
3 Cool White B	86.2	82.1	0.1	0.6	80.99	485.96
4 Cool White C	83.2	78.3	0.7	1.5	566.96	1214.90
5 Cool White D	87.3	84.8	0.0	0.2	0.00	161.99
6 Cool White E	86.1	82.8	0.0	0.5	0.00	404.97
7 Cool White F	85.9	80.6	0.2	1.0	161.99	809.94
8 Cool White G	90.0	85.3	0.0	0.1	0.00	80.99
9 Fiber-cement tile*	47.7	48.0	9.9	11.9	8018.37	9638.24

** Sample evaluated by Uemoto et al. (2010).*

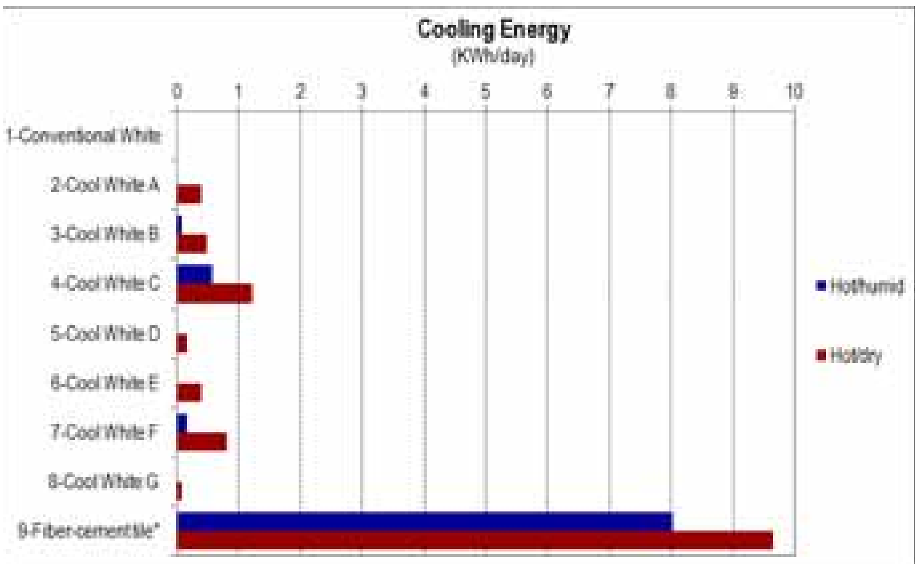


Figure 16 – Cooling energy estimated to restore the comfort inside the building (KWh/day).

It can be observed that the higher the roof solar reflectance is, the lower is the heat discomfort and the cooling energy need in buildings located in hot/dry and hot/humid climates in Brazil. For hot/dry climates, the need for cooling energy is higher than for hot/humid climates, as the results for the city of Belem and Sao Raimundo Nonato indicate.

The results demonstrated that the use of conventional or cool white coatings for cooling the roof surfaces are efficient in reducing the heat discomfort inside buildings located in hot climates. According to the results, a building with fiber-cement roofing with roof solar reflectance of 48% presents about 8 KWh/day of cooling energy need for the summer design day in Belem and 9.6 KWh/day for the hot and dry climate of Sao Raimundo Nonato. If this roof was painted with a conventional or cool white coating (solar reflectance higher than 80%), the heat discomfort and the cooling energy need could be significantly reduced in this building, offering comfort conditions for the occupants and less energy consumption for cooling the building.

4. Conclusions

This study demonstrated the effect of using reflective materials on improving the thermal comfort conditions for buildings located in cities with hot climates in Brazil. It was found that painting the roof surface with white solar-reflective paint is a very efficient way to reduce heat discomfort conditions for a single-story building located in cities with hot/humid and hot/dry climates.

Surface temperatures measured for samples exposed to the sun demonstrated that the solar reflectance of the paints directly affects the thermal performance of painted surfaces, evidencing that the higher the paint solar reflectance is, the lower is the building surface temperature, mainly for roofs, as the research results indicate. It can be observed that the great potential of using white paints filled with ceramic microspheres is due to the high solar reflectance they present, and not necessarily because of the presence of ceramic microspheres.

Furthermore, a simulation study was carried out aiming to assess the impact of using white solar-reflective coatings on roofs on the thermal comfort conditions in residential buildings located in hot climates. It was found that an increase in the roof solar reflectance from 48% to higher than 80% resulting from the application of a white coating can significantly reduce or even eliminate the cooling energy need for buildings located in hot and dry or hot and humid climates in Brazil.

In summary, the use of white paints on roof surfaces is an efficient passive solution for buildings located in tropical and hot climates. This solution can contribute to increase thermal comfort by lowering surface temperatures as well as indoor air temperatures and, consequently, reducing energy demand for cooling.

5. References

ASTM, 1996. E903-96: standard test method for solar absorptance, reflectance, and transmittance of materials using integrating spheres. ASTM International.

ASTM, 2003. G173-03: standard tables for reference solar spectral irradiances - direct normal and hemispherical on 37° tilted surface. ASTM International.

ASHRAE, 2004. ASHRAE 55-2004: thermal environmental conditions for human occupancy. ASHRAE, Atlanta.

ABNT, 2005. NBR 15220-3 – Thermal performance in buildings – Brazilian bioclimatic zones and building guidelines for low-cost houses. ABNT. Rio de Janeiro. (In Portuguese).

ABNT, 2008. NBR 15575: residential buildings up to five storied - Performance. ABNT, Rio de Janeiro. (In Portuguese).

BEN, 2007. Balanço Energético Nacional (National Energy Stock). In Portuguese. Brazil.

Dornelles, K. A.; Roriz, V.; Roriz, M., 2007. Determination of the solar absorptance of opaque surfaces. In: 24th International Conference on Passive and Low Energy Architecture, 2007, Singapore. Proceedings of the 24th PLEA. Singapore: Department of Architecture, NUS; 2007. v.1, p.452-459

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

Golden, J. S., 2003. The built environment induced urban heat island effect in rapidly urbanizing arid regions: a sustainable urban engineering complexity. Journal of Integrative Environmental Sciences, v.1, n.4, pp.321-49.

Jayasinghe, M. T. R.; Attalage, R. A.; Jayawardena, A. I., 2003. Roof orientation, roofing materials and roof surface colour: their influence on indoor thermal comfort in warm humid climates. Energy for Sustainable Development, v.7, n.1.

Jo, J. H.; Carlson, J. D.; Golden, J. S.; Bryan, H., 2010. An integrated empirical and modeling methodology for analyzing solar reflective roof technologies on commercial buildings. Building and Environment, v.45, pp.453–460.

Martins, F. R.; Pereira, E. B.; De Abreu, S. L.; Colle, S., 2005 Mapas de irradiação solar para o Brasil – Resultados do Projeto SWERA. In: Simpósio Brasileiro de Sensoriamento Remoto, 12, 2005, Goiania. Proceedings... Goiania. (In Portuguese).

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, v.40, pp. 2224-2235.

SZOKOLAY, S. V., 1987. Thermal design of buildings. Canberra: Raia Education Division.

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, v. 39, pp. 1167–1174.

Taha, H.; Akbari, H.; Rosenfeld, A.; Huang, J., 1988. Residential cooling loads and the urban heat island – the effects of albedo, Building and Environment, v. 23, No. 4, pp. 271-283.

Uemoto, K. L.; Sato, N. M. N.; John, V. M., 2010. Estimating thermal performance of cool colored paints. Energy and Buildings, v.42, pp. 17-22.

UNEP, 2007. Building and climate change: status, challenges and opportunities. United Nations Environment Program. Available in: <http://www.unglobalcompact.org/docs/issues_doc/Environment/climate/Buildings_and_climate_change.pdf>. Access: 12 sep. 2010.

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