http://dx.doi.org/10.1590/0104-1428.1869

# Development of paints with infrared radiation reflective properties

**Eliane Coser[1*], Vicente Froes Moritz[1], Arno Krenzinger[2] and Carlos Arthur Ferreira[1]**

*[1]Laboratório de Materiais Poliméricos – LAPOL, Programa de Pós-Graduação em Engenharia de Minas, Metalúrgica e de Materiais – PPGE3M, Universidade Federal do Rio Grande do Sul – UFRGS, Porto Alegre, RS, Brazil*

*[2]Laboratório de Energia Solar – LABSOLAR, Programa de Pós-Graduação em Engenharia Mecânica – PROMEC, Universidade Federal do Rio Grande do Sul – UFRGS, Porto Alegre, RS, Brazil*

**cosereliane@yahoo.com.br*

## Abstract

Large buildings situated in hot regions of the Globe need to be agreeable to their residents. Air conditioning is extensively used to make these buildings comfortable, with consequent energy consumption. Absorption of solar visible and infrared radiations are responsible for heating objects on the surface of the Earth, including houses and buildings. To avoid excessive energy consumption, it is possible to use coatings formulated with special pigments that are able to reflect the radiation in the near- infrared, NIR, spectrum. To evaluate this phenomenon an experimental study about the reflectivity of paints containing infrared-reflective pigments has been made. By irradiating with an IR source and by measuring the surface temperatures of the samples we evaluated: color according to ASTM D 2244-14, UV/VIS/NIR reflectance according to ASTM E 903-12 and thermal performance. Additionally, the spectral reflectance and the IR emittance were measured and the solar reflectance of the samples were calculated. The results showed that plates coated with paints containing IR-reflecting pigments displayed lower air temperature on the opposite side as compared to conventional coatings, indicating that they can be effective to reflect NIR and decrease the temperature of buildings when used in roofs and walls.

**Keywords:** *cool paints, near-infrared reflectance, solar spectral reflectance, cool pigments, colored reflecting pigments.*

## 1. Introduction

Solar energy plays an important role in economic development around the world. The wavelength of the light that reaches the Earth's surface conventionally ranges from 300 to 2500 nm. The human eye is sensitive to only a part of the electromagnetic spectrum. Pigments are colour compounds that are responsible to give colour to objects as they selectively absorb the visible light and reflect the remainder corresponding to its colour. Apart from the visible region, pigments also interact with other wavelengths of light in the electromagnetic spectrum[1-3].

Roughly 5% of the Sunlight that reaches the Earth's surface is in the form of ultraviolet (UV) (wavelength between 300 and 400nm) (see Figure 1) which is the main responsible by the photo degradation of organic materials including organic coatings. Around 42% of the solar energy occurs in the visible region of the electromagnetic spectrum. Different colours are detected by the optical human system in the wavelength range from 400 to 700 nm. Some 53% of the total solar energy is in the infrared region (IR) whose wavelength ranges from 700 to 2500nm. Heat is a direct consequence of either visible or infrared radiation incident on an object. The heat-producing region of the infrared radiation ranges from 700 to 1100 nm[1,4].

A roof with high solar reflectance (the ability to reflect sunlight) and high thermal emittance (the ability to radiate heat) remains cool in the sun, reducing demand for cooling power in air-conditioned buildings and increasing occupant comfort in unconditioned buildings. 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 especially during summer, resulting in more comfortable thermal conditions if the building is not air-conditioned[5,6].

The primary purpose of IR-reflective coatings is to keep objects cooler than they would be using conventional pigments. Normally the reflection of solar energy is empirically obtained by the use of white paints, which produce a beautiful effect but is little useful and acceptable in big cities. Normal paints containing titanium dioxide ($TiO_2$) as white pigments reflect visible and IR radiation very well[7]. $TiO_2$ is the most employed pigment in the formulation of paints; it is an ingredient which improves the quality of paint ensuring high coverage power, durability, brightness and opacity[8]. To avoid the monotonic effect that a totally white city could produce, there are coloured paints on the marked, but the normal pigments used in these paints have low reflectivity. Each pigment has distinct IR-reflective characteristics. In addition to their reflective properties, pigments can differ in their weatherability, chemical resistance, and other durability criteria.

Inorganic pigments infrared reflectors are colour pigments made of inorganic complexes, which reflect the wavelengths in the infrared region as well as selectively reflect visible light. The reflectivity and absorptivity are dependent of the pigment. Therefore, an infrared-reflective pigment may be in any colour and it can be synthesized by the calcination of a mixture of oxides, nitrates, acetates and even metal oxide at temperatures above 1000°C. At the calcination temperature the solids themselves become reactive, metal and oxygen ions rearrange to form new crystalline stable structure such as rutile or spinel[1,9]. The pigment particle size is of extreme importance to the NIR reflectance. Pigments consisting of smaller particles or nanoparticles significantly improve the reflective properties[10].

Libbra et al.[4] prepared an acrylic water based paint containing a mixture of a red $Fe_2O_3$ pigment and $TiO_2$ and applied it on terra-cotta tiles in Italy. They verified that even using a highly IR reflective pigment ($TiO_2$), the reflectance of the protective layer was not satisfactory. Ryan[11] has evaluated the total solar reflectance (TSR) of commercial cool pigments and Artic® pigments from Shepherd Colour Company[12] with different colours. They verified that mixing the Blue 211 with the Black 10C909, the reflectance decreased when he increased the amount of the black pigment. He recommended that formulators must be extremely careful during mixing the components of a paint in order to maintain IR reflectance, as even small amounts of IR-absorbing pigments can strongly reduce TSR. An extensive study of cool pigments has been conducted by Malshe and Bendiganavale[1]. They tried to produce IR reflective pigments similar to the commercials by calcination of mixtures of several oxides of metals as Ti, Co, Ni and Mn in different atomic proportions. None of their experiments resulted in significant IR reflectivity, demonstrating the complexity of the subject. They have used a very simple device to evaluate the difference of temperature attained by painted samples irradiated by an IR Lamp. Uemoto et al.[13] have used three commercial paints formulated by an industrial collaborator. The paints were similar in colour and have been applied on cement roof sheets. They measured the difference of temperature using a closed wood device and the results demonstrated a higher NIR reflectance for samples coated with cool paints compared to those coated with conventional paints.

New coatings that are coloured but still reflect sunlight and remain cooler are being developed using specialized cool pigments. These *smart* cool coatings decrease roof surface temperature, reducing the energy needed for cooling buildings and making unconditioned buildings more comfortable.

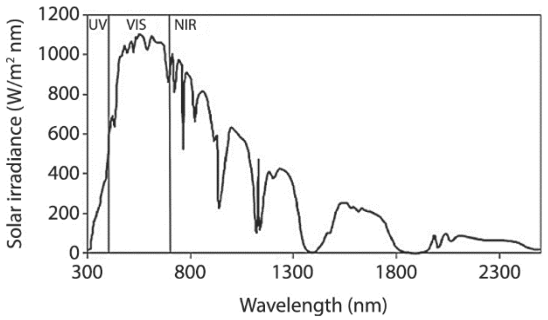


**Figure 1.** The solar spectrum[5]

In the present work a procedure similar to[1] has been adopted. In order to demonstrate that colours coatings can reflect sunlight and heat in a similar way to white coatings, paints in four colour were formulated at the laboratory with cool and conventional pigments and applied to fibre cement plates. The samples were characterised by measuring the colour, the spectral reflectance and the temperature in front and behind the samples. The diffuse reflectance and infrared emittance were measured and the solar reflectance of the samples was calculated.

## 2. Experimental

### 2.1 Preparation of paints

The materials were classified according to their thermal performance and physical properties in *cool* and *warm* materials. Eight samples were analysed: four *cool* paints tested in comparison to four samples similarly coloured prepared using conventional pigmented. The solvent-based paints (bi-component) were prepared in the laboratory using a Byk model Dispermat N1 disperser with a Cowles disk according to the basic formulation shown in Table 1, changing only the pigment. The materials were applied with a brush, in two layers. The final dry thicknesses were 75 +/–µm. Each paint was tested in at least three samples.

The pigments used in the production of reflective paints were provided by Shepherd Colour Company representative office in Brazil. In Table 2 are described the pigments and the chromospheres that each belongs pigment used for the production of paint[12].

All the coatings were applied on 20 x 20 x 0.8 cm fibre cement plates. The aspect of the samples is shown in Figure 2.

**Table 1.** Formulation of paints produced in laboratory.

| COMPONENT 1 | | PARTS (%) |
|---|---|---|
| Resins | Hydroxylated acrylic | 50.00 |
| Solvent | Organic: Ethyl glycol acetate, Ethyl acetate and Xylene | 27.50 |
| Thickener | Tixogel | 0.20 |
| Dispersant | Additive BYK 108 | 0.30 |
| Pigment | $TiO_2$ | 22.00 |
| | Total | 100.00 |
| **COMPONENT 2** | | **PARTS (%)** |
| Catalyst | Isocyanate AQ - 6008 | 38.00 |
| Solvent | Organic | 62.00 |
| | Total | 100.00 |

**Table 2.** Description of the pigment.

| Pigment | Chromophores | Description samples |
|---|---|---|
| Yellow 346 | Chrome Antimony | Yellow |
| Brown 157 | Zinc Iron Chromite | Brown 1 |
| Brown Rosse 208 | Iron oxide | Brown 2 |
| Black 28 | Copper Chromite | Black |

### 2.2 Characterization of coatings

A UV/Vis/NIR spectrophotometer (Varian Carry 5000) was used for measure the spectral reflectance of the samples[14]. The spectrophotometer was fitted with a 150 mm diameter integrating sphere (Labsphere DRA 1800) which collects both specular and diffuse radiation. The reference reflectance material used for the measurement was a PTFE plate, according to ASTM Standard E 903-12[5,15].

Colours of samples were measured according to the CIE (Commission Internationale de l'Eclairage) that is the regulatory body responsible for international recommendations for photometry and colorimetry[16], which is being presently widely used to characterize the colour of the paints that were produced in the laboratory (reflective paint) compared with the commercial paints.

In this system, the values measured are L*, a* and b* and are called CIELAB. Each colour is represented by the coordinates in a three-dimensional system generating a set of three members (Figure 3).

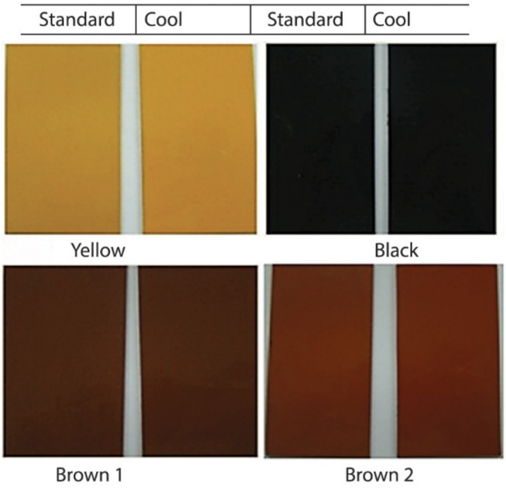


**Figure 2.** Samples painted with cool and conventional pigments with visual similar colour.

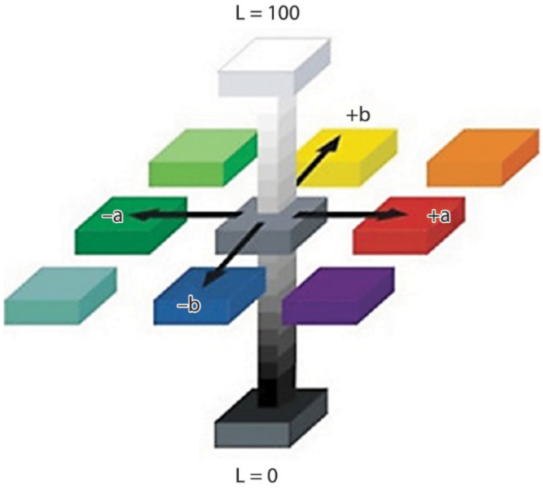


**Figure 3.** CIE colour system L*, a*, b*[17].

The vertical L* axis represents the differences between light (L*=100) at the top and dark (L*=0) at the bottom. The axis a* displays the difference between red (+a*) and green (–a*), while b* corresponds to the difference between yellow (+b*) and blue (–b*).

Colour difference (ΔE*) between two colour points in the CIELAB space are calculated as the Euclidean distance between their locations in the three-dimensional space defined by L*, a*, and b*[18] . Thus, mathematically, it is calculated using the formula[16]:

$$\Delta E = \sqrt{\left(\Delta L^{*}\right)^{2} + \left(\Delta a^{*}\right)^{2} + \left(\Delta b^{*}\right)^{2}} \tag{1}$$

Measurements of colour were done in dry films according to ASTM D 2244-14[19], using a Byk Gardner model Spectro-guide Portable Spectrophotometer.

The painted plates were exposed to a Philips PRA 38 IR Red (150W 230V reference E27 ES) infrared lamp. The distance between the sample and the lamp was maintained at 30 cm. Two thermocouples were used to record the temperatures, one thermocouple in front and the other at the back of the plate. The plates were allowed under infrared lamp during an hour to equilibrate the temperature. After this period the temperature was recorded. The same procedure was adopted for the uncoated sample. The difference between the temperature in front (coated) and in the back (uncoated) side of the samples was used as an indicative of the performance of the pigments (infrared-reflective or not). Figure 4 shows the experimental setup for simulating the infrared reflectivity of pigments.

The temperature of the room was kept constant in order to avoid accumulation of heat in this space and to assure that the heat absorbed by the fibre cement plates was exclusively by irradiation and not by convection of the air in contact with the inner surface of the plates.

The solar reflectance ($\dot{\rho}$) and the thermal emittance ($\varepsilon$)[20] of a roof surface are important surface properties affecting the roof temperature, which, in turn, drives the heat flow through the roof[21,22] The emissivity of the samples was also measured using the device model AE Emissometer Devices & Services, according to ASTM standard C1371-10.

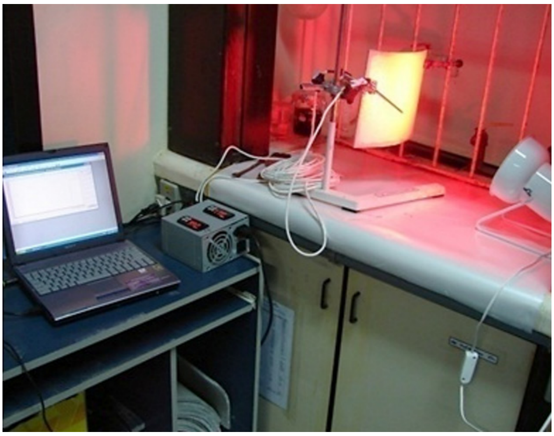


**Figure 4.** Experimental setup for measuring temperature as IR lamps irradiates coated cement plates.

## 3. Results and Discussion

### *3.1 Colour characterization of paint films*

Although visually the samples of the same colour were quite similar (Figure 2), the CIELAB results presented in Table 3 display significant differences between cool colour paints and standard paints. These values indicate that the lower L* of the paint, the lower is its luminosity[18,23]. L* values indicate the difference in luminosity between samples. The data obtained show that standard sample presented lower luminosity than cool sample.

According to Table 3, L* of Yellow paint is higher for the reflective sample than for standard paint. Despite visually having the same colour, as the b* values are positive and high, ΔE indicates the existence of a colour difference between these Yellow coloured paints.

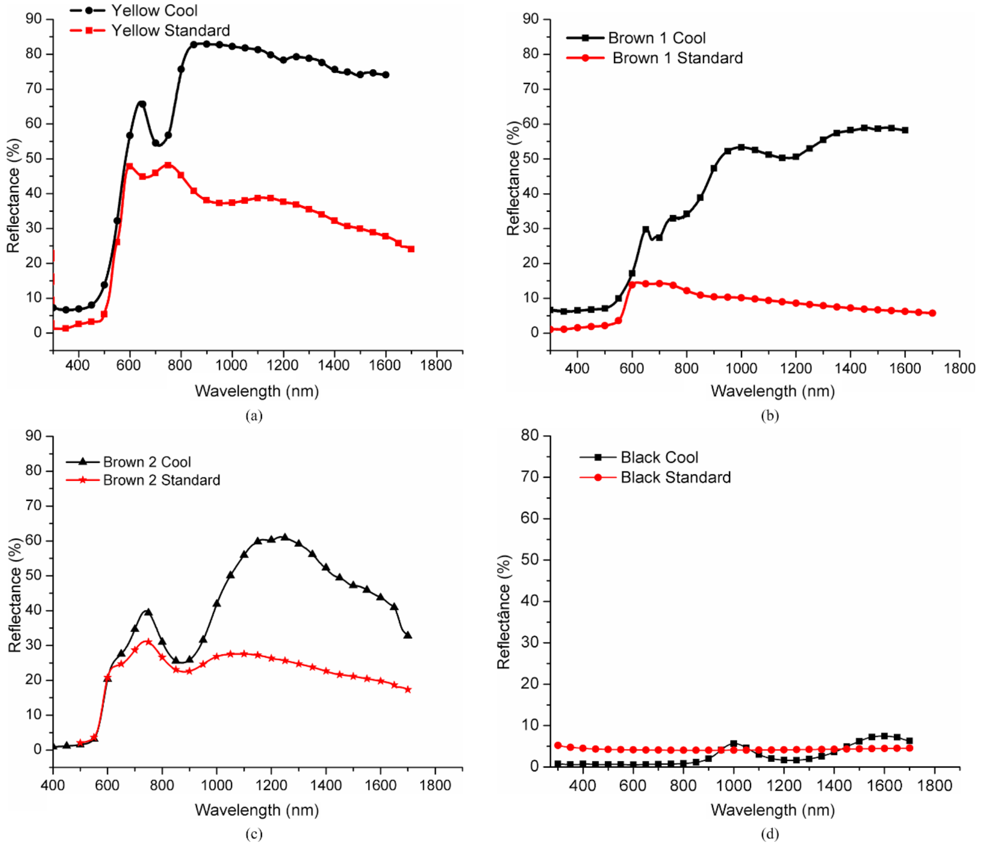
Standard and cool Black paints are very similar, as ΔE is 0.85 ± 0.10 (it would be zero if the colours were exactly the same). The Brown 1 paints presented ΔE=1.51 ± 0.18, but displayed similar lightness L* values (37.8 and 38.2). The Brown 2 paint displayed quite different colours (ΔE=2.51 ± 0.30) and this paint is more reddish than Brown 1 because a* parameter of these sample (a*~ 18-19) are higher than brown 2 sample (a*~ 27-29).

### *3.2 The UV, VIS and NIR reflectance*

The spectrophotometric reflectance spectra (UV, VIS, and NIR) of all samples are shown in Figure 5. Measurements were done according to ASTM E 903-12. The reflectance of

**Table 3.** Colour characterization of standard and cool paints.

| Sample | Colour coordinates | | | |
|---|---|---|---|---|
| | L* | a* | b* | ΔE |
| Standard | 61.74±0,32 | 20.62±0,18 | 52.52±0,22 | 3.05 ± 0.37 |
| Yellow | 64.35±0,16 | 22.64±0,15 | 53.19±0,15 | |
| Cool Yellow | | | | |
| Standard Black | 28.48±0,17 | –0.75±0,05 | –0.99±0,10 | 0.85 ± 0.10 |
| Cool Black | 28.11±0,22 | -0.85±0,07 | –0.72±0,08 | |
| Standard Brown 1 | 37.84±0,11 | 18.44±0,11 | 16.44±0,05 | 1.51 ± 0.18 |
| Cool Brown 1 | 38.23±0,04 | 19.65±0,12 | 17.73±0,11 | |
| Standard Brown 2 | 41.20±0,28 | 27.61±0,09 | 22.84±0,20 | 2.51 ± 0.30 |
| Cool Brown 2 | 44.63 ±0,06 | 29.75±0,16 | 23.15±0,015 | |



(a) (b) (c) (d)

**Figure 5.** Reflectance of paints in the UV/Vis/NIR region (a) Yellow, (b) Brown 1, (c) Brown 2 and (d) Black.

**Table 4.** Temperature in front and behind painted plates.

| Sample | Front of Panel (°C) | Behind Panel (°C) | $\Delta T_1$ (°C) | $\Delta T_2$ (°C) |
|---|---|---|---|---|
| Uncoated | 51.3 ± 0.21 | 40.8 ± 0.12 | 10.5 | |
| Standard | 56.2 ± 0.77 | 40.3 ± 0.78 | 15.7 | |
| Yellow | | | | |
| Cool | 51.7 ± 0.3 | 39.4 ± 0.10 | 12.3 | –0.9 |
| Yellow | | | | |
| Standard Black | 61.6 ± 0.07 | 45.8 ±0.20 | 15.8 | |
| Cool Black | 59.5 ± 0.14 | 45.3 ± 0.15 | 14.3 | –0.5 |
| Standard Brown 1 | 60.3 ± 0.70 | 40.3 ± 0.21 | 20.0 | |
| Cool Brown 1 | 54.3 ± 1.20 | 41.3 ± 0.85 | 13.1 | +1.0 |
| Standard Brown 2 | 58.6 ± 0,07 | 44.6 ± 0,07 | 14.0 | |
| Cool Brown 2 | 53.9 ± 0.08 | 41.9 ± 0.07 | 12.0 | –2.7 |

$\Delta T_1$: $T_{front}$ - $T_{behind}$; $\Delta T_2$: $T_{behind\ cool}$ - $T_{behind\ standard}$.

all points sample is very low at the UV region (around 5%). As expected, Figures 5a, b and c show that the cool paints presented higher reflectance than standard paints in the VIS region, namely between 2-3% at 400nm and 10-40% for standard and 28-60% for cool paints at 700nm. Black paint (Figure 5d) present very low VIS reflectance.

The NIR spectra display remarkable differences. Yellow and Brown 1 reflectance spectra of paints prepared with cool and conventional pigments (Figure 5a and Figure 5b) show differences that reach some 35% (Yellow) and 40% (Brown1) demonstrating clearly the reflective proprieties of cool pigments. Brown 2 cool paint (Figure 5c) is less reflective than Yellow and Brown1 cool paint. The Brown 2 cool and standard paints showed reflectance that are closer than for the other samples. These results show clearly that Brown 2 cool pigment is less efficient in reflect VIS and NIR radiation than Yellow and Brown 1 pigment.

This high NIR "invisible" reflectance displayed by the samples explains the fact that the cool colour are characterized by high reflectance values. Sunlight is more intense in the visible region, but it also emits a substantial amount of energy in the invisible ultraviolet (UV) and near-infrared (NIR). In fact, about half percent of all solar power that reaches the Earth's surface arrives as invisible near-infrared radiation.

The reflective ability of the samples to reflect IR radiation was tested by measuring the temperature in front of and behind painted fibre concrete plates using the device shown in Figure 3. The Table 4 shows the results of the temperatures measured for the coatings.

It is clear from Table 4 that even uncoated plates made with fibre cement are able to display different temperatures on the two sides if they are irradiated by an IR lamp. The temperatures behind the panels for all cool pigments are lower than the temperatures for conventional pigments, except for Brown 1 (see also $\Delta T_1$). This behaviour is the consequence of the ability of cool pigmented coatings to reflect IR radiation from the lamp, reducing the temperature behind the panels. For Brown 1 $\Delta T_1$ is the highest among all paints, even if the temperature in front of the panel is the highest of all sample.

As a consequence, the lowest temperature behind the panels has been measured to the yellow cool sample (39.4 °C) and the higher temperature to the standard Black sample (45.8°). Yellow pigment demonstrated to be a good choice to reflect IR radiation in external roof of buildings. As another form to express the behaviour of cool paints, the difference of temperature behind the panels coated with cool and standard paints ($\Delta T_2$) have been calculated and the cool Brown 2 sample showed the higher value (–2.7 °C) indicating it is also a good choice to external roof colour that reflect IR radiation.

**Table 5.** Solar reflectance and emissivity of paints.

| Sample | Emissivity | Solar reflectance |
|---|---|---|
| Cool Yellow | 0.92 | 0.52 |
| Standard Yellow | 0.87 | 0.31 |
| Cool Black | 0.90 | 0.06 |
| Standard Black | 0.91 | 0.05 |
| Cool Brown 1 | 0.90 | 0.29 |
| Standard Brown 1 | 0.92 | 0.85 |
| Cool Brown 2 | 0.89 | 0.24 |
| Standard Brown 2 | 0.89 | 0.18 |

The emissivity is the measure of an object's ability to emit infrared energy. Emitted energy indicates the temperature of the object. Emissivity can have a value from 0 (shiny mirror) to 1.0 (Blackbody). The emissivity (ε) is a surface characteristic of each material. The higher the emissivity, higher the heat loss by the substrate. The emissivity (ε) of all paints is in the range 0.87 to 0.92 (Table 5), indicating that all paints have an appropriate behaviour to be used as a roof coating as they are able to loose heat.

The solar reflectance results shown in Table 5 were calculated according to the standard ASTM G173-12. They were obtained by the integral of the data in Figure 5 with reference to Solar Spectral Irradiances.

When applying an infrared reflective coating or cool coating, one must maximize solar reflectance and emissivity, and minimize all contamination by infrared absorbing materials. It is observed in Table 5 that the commercial coatings have lower reflectance than cool coatings, with the exception of the coating Standard Brown 1.

The results displayed at Table 5 show that coatings prepared with cool pigments emit infrared radiation more efficiently than the standard coatings.

## 4. Conclusions

Eight types of coatings were studied, four coatings containing *cool* pigments and four coatings containing conventional pigments. Their colours were very similar, as measured by the CIE standard. The use of cool pigments in paint formulations allows the development of coatings with similar reflection in the colours (VIS range) but higher reflectance in NIR radiation. Cement fibre plates coated with cool paints displayed lower temperature than standard coated panels when irradiated by an IR lamp. Consequently, if roofs and walls are coated with paints containing cool pigments, the temperature inside the buildings and houses could be maintained lower than if they were painted with conventional paints. In this way, the cool-coloured paints can be employed as an alternative to white paint and can improve thermal comfort conditions of low-cost housing, industrial and residential buildings constructed with fibre-cement roofing sheets.

## 5. Acknowledgements

This work was supported by CNPq. The authors would like to thank Águia Química S.A. for providing the resin and Color Net for providing the pigments used. Joe Tonolli is thanked for preparing the matched standard coloured paints used in this work.

## 6. References

1. Malshe, V., & Bendiganavale, A. (2008). Infrared reflective inorganic pigments. *Recent Patents on Chemical Engineering*, *1*(1), 67-79. http://dx.doi.org/10.2174/2211334710801010067.
2. Levinson, R., Berdahl, P., & Akbari, H. (2005). Solar spectral optical properties of pigments— art I: model for deriving scattering and absorption coefficients from transmittance and reflectance measurements. *Solar Energy Materials and Solar Cells*, *89*(4), 319-349. http://dx.doi.org/10.1016/j.solmat.2004.11.012.
3. Kaur, B., Quazi, N., Ivanov, I., & Bhattacharya, S. N. (2012). Near-infrared reflective properties of perylene derivatives. *Dyes and Pigments*, *92*(3), 1108-1113. http://dx.doi.org/10.1016/j.dyepig.2011.06.011.
4. Libbra, A., Tarozzi, L., Muscio, A., & Corticelli, M. A. (2011). Spectral response data for development of cool coloured tile coverings. *Optics & Laser Technology*, *43*(2), 394-400. http://dx.doi.org/10.1016/j.optlastec.2009.07.001.
5. Levinson, R., Akbari, H., & Berdahl, P. (2010). Measuring solar reflectance—Part I: Defining a metric that accurately predicts solar heat gain. *Solar Energy*, *84*(9), 1717-1744. http://dx.doi.org/10.1016/j.solener.2010.04.018.
6. Zinzi, M., Carnielo, E., & Agnoli, S. (2012). Characterization and assessment of cool coloured solar protection devices for Mediterranean residential buildings application. *Energy and Building*, *50*, 111-119. http://dx.doi.org/10.1016/j.enbuild.2012.03.031.
7. Song, Z., Zhang, W., Shi, Y., Song, J., Qu, J., Qin, J., Zhang, T., Li, Y., Zhang, H., & Zhang, R. (2013). Optical properties across the solar spectrum and indoor thermal performance of cool white coatings for building energy efficiency. *Energy and Building*, *63*, 49-58. http://dx.doi.org/10.1016/j.enbuild.2013.03.051.
8. DuPont (2007). *DuPont™ Ti-Pure® titanium dioxide: titanium dioxide for coatings*. U.S.A.: DuPont. Retrieved in 15 May 2014, from http://www2.dupont.com/Titanium_Technologies/pt_US/tech_info/literature/Coatings/CO_B_H_65969_Coatings_Brochure.pdf
9. Fang, V., Kennedy, J., Futter, J., Manning, J., (2013). *A review of near infrared reflectance properties of metal oxide nanostructures* (GNS Science Report). New Zealand: Institute of Geological and Nuclear Sciences.
10. Liu, J., Lu, Y., Liu, J., Yang, X., & Yu, X. B. (2010). Investigation of near infrared reflectance by tuning the shape of SnO2 nanoparticles. *Journal of Alloys and Compounds*, *496*(1-2), 261-264. http://dx.doi.org/10.1016/j.jallcom.2010.01.053.
11. Ryan, M. (2005). *Introduction to IR-reflective pigments*. *Paint & Coatings Industry*, 170-176.
12. Shepherd Color Company (2001). *Select a product for more information*. Cincinnati: Shepherd Color Company. Retrieved in 15 May 2014, from http://www.shepherdcolor.com/Products/ColorChart.aspx
13. Uemoto, K. L., Sato, N. M. N., & John, V. M. (2010). Estimating thermal performance of cool colored paints. *Energy and Building*, *42*(1), 17-22. http://dx.doi.org/10.1016/j.enbuild.2009.07.026.
14. Agilent Technologies (2000). *Molecular spectroscopy*. Santa Clara: Agilent Technologies. Retrieved in 16 May 2014, from http://www.chem.agilent.com/en-US/products-services/Instruments-Systems/Molecular-Spectroscopy/Cary-5000-UV-Vis-NIR/Pages/default.aspx
15. American Society for Testing and Materials (2012). *ASTM E903-12: Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres*. West Conshohocken: ASTM.
16. Khan, M. A. I., Ueno, K., Horimoto, S., Komai, F., Someya, T., Inoue, K., Tanaka, K., & Ono, Y. (2009). CIELAB color variables as indicators of compost stability. *Waste Management*, *29*(12), 2969-2975. http://dx.doi.org/10.1016/j.wasman.2009.06.021. PMid:19781930.
17. Quimanil (2010). *Colorimetria*. São Paulo: Quimanil. Retrieved in 7 October 2014, from http://www.quimanil.com.br/empresa/informacoes_detalhe.php?id=7
18. García-Marino, M., Escudero-Gilete, M. L., Heredia, F. J., Escribano-Bailón, M. T., & Rivas-Gonzalo, J. C. (2013). Color-copigmentation study by tristimulus colorimetry (CIELAB) in red wines obtained from Tempranillo and Graciano varieties. *Food Research International*, *51*(1), 123-131. http://dx.doi.org/10.1016/j.foodres.2012.11.035.
19. American Society for Testing and Materials (2014). *ASTM D2244-14: Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates*. West Conshohocken: ASTM.
20. Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, *85*(12), 3085-3102. http://dx.doi.org/10.1016/j.solener.2010.12.023.
21. Suehrcke, H. E. L., Peterson, E. L., & Selby, N. (2008). Effect of roof solar reflectance on the building heat gain in a hot climate. *Energy and Building*, *40*(12), 2224-2235. http://dx.doi.org/10.1016/j.enbuild.2008.06.015.
22. Henninger, J. H. (1984). *Solar absorptance thermal emittance of some common spacecraft thermal-control coatings*. Washington: Scientific and Technical Information Branch. Retrieved in 8 October 2014, from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19840015630.pdf
23. Korifi, R., Le Dréau, Y., Antinelli, J. F., Valls, R., & Dupuy, N. (2013). CIEL*a*b* color space predictive models for colorimetry devices--analysis of perfume quality. *Talanta*, *104*, 58-66. http://dx.doi.org/10.1016/j.talanta.2012.11.026. PMid:23597889.

*Received: July 29, 2014*
*Revised: Oct. 21, 2014*
*Accepted: Jan. 15, 2015*