HEAT REFLECTING PAINTS AND A REVIEW OF THEIR ADVERTISING MATERIAL

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ABSTRACT

Heat reflecting paints are usually used on buildings as external paints to reduce the heat load from solar irradiation. They can also be used on external pipework where the pipe contents such as water, oil or similar should be protected from excessive temperatures.

This paper reviews the current advertising material and published on the internet by heat reflecting paint suppliers including those who use hollow silica/ceramic spheres. The aim of the paper is to give a better understanding of how they function and of the benefits of this type of paint.

The way that they function is not by being, as claimed, an insulation layer similar to heat shuttle ceramic tiles or thermal insulation batts. It is actually by the inclusion of low refractive index 'bubbles' within the spheres acting as shorter wavelength infra-red scattering centres within the paint body. The data in advertising material that is supplied in the form of reflectance spectra and temperature measurements supports the claims of lowered external surface temperatures. Based on the available data, this paper shows that these paints have virtually no insulative effect as such. The benefits result from lower heat radiation into the roofspace or pipework and lower conduction/convection from the roof or pipe surface irradiated by sunlight.

Generally, the most cost-effective way to minimise surface heating from solar radiation is to use standard pure white acrylic paints. In critical situations, the expense of a heat reflective white paint may be justified. In cases where glare from pure white paints is likely to be problematic then as light as possible a colour of heat reflective paint should be used. The increased heat gain through using paints darker than pure white can be partly mitigated by using heat reflecting paint additives with hollow ceramic/silica microspheres and/or using pigments that scatter infra-red radiation effectively.

INTRODUCTION

Heat reflective paints have been available for the last fifteen years. They are beginning to be used in industrial and architectural applications to give significant cost savings through reduced energy use for temperature control. These paints are used to reflect the heat component of sunlight, which leads to a reduction of exterior surface temperatures and thus the heat load on buildings and pipework.

Many of these paints employ silica/ceramic microspheres to reflect infra-red radiation. The area has hardly been covered in the scientific or engineering literature. This paper explains how they function and is a review of some of the advertising material and claims in the heat reflective paint field.

The main use of heat reflective paints is to reduce the absorption of infra-red radiation at surfaces exposed to sunlight without changing the visible colour. Figure 1 shows the solar spectrum from 300 nm to 2.5 μm and highlights the portion that is visible to the

human eye representing nearly half of the incident energy with infra-red being most of the remainder.

Any surface will have varying reflectance at wavelengths across the spectrum. Radiation that is not reflected will be absorbed at the surface, leading to increased surface temperature. If the reflectances at different wavelengths are weighted according to that of the solar spectrum at ground level with Air Mass 1.5 (Renewable Resource Data Center, accessed 12/6/2010), we can arrive at a single value of Total Solar Reflectance (TSR). It is possible to increase reflected sunlight by increasing surface reflectance in the infra-red, and hence the TSR, without changing the perceived colour. A dark colour will still absorb strongly in the visible part of the solar spectrum contributing to higher surface temperatures than lighter colours.

Surface temperatures are a function of the emissivity, a material property that determines the long wavelength infrared radiation emitted from a surface. An emissivity of unity maximises this radiation, reducing surface temperatures. Bright metal roofs become hot despite high reflectivity because the emissivity is low. Many other materials have emissivities near 0.9.

In 1908, Mie in Germany published a paper on light scattering from particles approximately the same size as the wavelength of light (Mie, 1908). Mie scattering is quite different to the highly wavelength-dependant Rayleigh scattering from molecules in the atmosphere that lead to the characteristic blue colour of the sky. Mie scattering depends upon the difference in refractive index (RI) of the scattering particle from the medium that light is traversing, the diameter of the scatterer and the wavelength of the light. From each Mie scattering there will be a range of angles where light is scattered and some will be scattered in a backwards direction.

Figure 2 shows the scattering on a log scale from a TiO_2 particle in a paint film. Once the light has been scattered several times within the paint film it can be reflected back out of the paint film without reaching the substrate provided that the film is thick enough and the particles or the paint medium do not absorb the light.

An example of particles having higher RI than the medium is given with clouds. White light can be seen scattered out of the cloud from multiple water droplets or ice particles. It allows us to see the total volume of the cloud where there are Mie scatterers.

An alternative situation occurs when the RI of the 'particle' is less than that of the medium. Figure 3 provides an example of this, where microscopic air bubbles are entrained in water. We can see through the water to the milky volume, where the small underwater bubbles are reflecting ambient light back out of the water. Similarly, studies have been made of light scattering from small bubbles in water-based bioreactors (Berberoglu et al, 2007). These examples with water are similar to the effect achieved in the infra-red for paint that includes hollow microspheres with the paint medium as the bulk material.

Under typical standard paint formulation with 1 μm TiO_2 particles in paint there will be approximately 11 percent backscattering efficiency at 450 nm (blue light) reducing to 1.6 percent at 2 μm infra-red wavelengths. Doubling the TiO_2 particle size boosts the infra-red backscattering at 2 μm wavelength to 4.4 percent (Prahl, accessed 17/6/2010).

With heat reflective paints, more heat from the sun is reflected outwards and the emissivity is higher than for metals, dissipating more of any heat that has been absorbed back to the sky. This applies equally well to buildings, pipes transporting oil or water; insulated pipes used to transport refrigerated wine externally from one storage vat to another, insulated outdoor storage vats and hulls of ships that are subjected to incident sunlight.

The purpose of using heat reflective paints is to provide a radiative barrier to minimise surface heating rather than creating an insulative layer to reduce the conductive flow of heat. Despite advertising material to the contrary, it will be seen below that thermal conduction plays an insignificant role compared with the importance of Total Solar Reflectance in minimising temperature build-up.

One method of reflecting infra-red radiation is to use normal types of pigment particles in the paint and select those that scatter strongly in the infra-red when carefully formulating the paint to give a desired visible colour outcome. An example of an Australian company with this approach is the Dulux range of InfraCOOL paints (Dulux, accessed 27/5/2010). ASTEC with their Energy Star paints (ASTEC, accessed 14/6/2010) will not divulge their technologies but it is believed that they also use specialised pigments, possibly mixed-metal oxides to gain high infra-red reflectance.

Another approach to creating a heat reflective paint is by adding hollow microspheres that do not scatter light in the visible part of the spectrum but scatter effectively in the infra-red (Dombrovsky, 2005), (Dombrovsky, *et al*, 2005), (Dombrovsky, *et al*, 2007). In Australia, the microsphere additives appear to be dominated by INSULADD and Thermilate which both come from the same source. Examples of a company using the INSULADD/Thermilate approach in Adelaide is Acryloc's additive products (Acryloc, accessed 16/6/2010) plus their roof formulations (Acryloc, accessed 15/6/2010). Acryloc infer in their documentation that they combine the first approach with the second for their tinted colour formulations.

Another approach is to formulate the paint with either one or both of the above two methods while making sure that emissivity is high in the 8 to 13 μm wavelength region. There is a transmission window there in the atmosphere relatively independent of moisture level so that heat can be effectively removed from the surface, and even the building, by radiative transfer processes. The broad peak for black body radiation for surface temperatures between –10 °C and +100 °C lies in this region and extends from wavelengths of 3 μm to 40 or 50 μm. An example of an Australian company that uses this approach is SkyCool. (SkyCool, accessed 24/05/2010).

In the US, there are several companies producing hollow microspheres including INSULADD, Hy-Tech and 3M. The first two of these are spinoff companies from NASA projects.

Heat reflective paints rely on maximising reflection of the whole solar spectrum at the surface. This requires minimising any absorption and therefore any contaminants trapped at the surface that absorb the solar radiation. A gloss surface will be more likely to have contaminants washed off by rain or blown away than a matte or low-sheen paint that can trap absorbing particles in its surface crevices and thereby lower solar reflectance over time. Generally a thicker layer is required to produce a layer opaque to infra-red radiation because of less efficient scattering at the longer wavelengths. A 'membrane' having a thickness of 150 μm or more would typically be required for a heat reflective paint.

ADVERTISING

It is difficult to advertise to non-technical people about infra-red, heat radiation as distinct from heat conduction and, in particular, about effects that are dependent upon emissivity. As a result, the advertising material is often not technically correct in explaining how these paints function.

The microspheres are claimed by Hy-Tech to have an R-value of 250 because of the vacuum inside (Hy-Tech, accessed 13/6/2010) This neglects the conductivity of the

ceramic shell with shell thickness approximately 10 percent of microsphere diameter and neglects the paint medium the microsphere is used in. The microspheres are referred to (Hy-Tech, accessed 14/6/2010) as creating a tightly packed film of the 'thermos bottle'-like cells. A similar idea is found in cartoons (INSULADD, accessed 10/6/2010) such as the one shown in Figure 4. To be thermally effective as insulation they would not be able to have paint medium in the interstitial volume or there would be substantial thermal conduction through the layer. The reality is that paint layers with more than approximately 40 percent of the total volume made up with pigments and microspheres would have insufficient cohesion to be a viable layer against abrasion and would not provide corrosion protection. INSULADD recommends one part by volume of the additive to four parts of paint and this supports the statement here that the interstitial volumes are not empty.

Claims by ASTEC (ASTEC, accessed 14/6/2010, p. 3) that 'Energy Star coatings reflect fully 50 percent of Solar energy'. This would infer that there is 100 percent reflectance over the whole infrared spectrum beyond 700 nm in the case of black Energy Star paint because the reflectance in the visible region is less than 10 percent. It is definitely not the case in Figure 5 here taken from the same ASTEC page.

Companies selling heat reflective paints often set up test boxes using panels painted in standard and heat reflective versions of paint with, for example, 450 W infra-red lamps to demonstrate the cooler heat reflective version (ASTEC, accessed 14/6/2010, p. 2). The relatively short distance usually used from lamp to test panel plus the greater intensity weighting to infra-red radiation mean that panels with conventional and heat reflective paints will both be much hotter than in sunlight and the differences will be greater than normally expected. The lamps do not reproduce the solar spectrum and exaggerate the temperature differences compared with summer sunlight or lamps correctly simulating the solar spectrum and having an intensity of approximately 1 kW/m^2.at the test sample.

The Australian-based Heat Reflective Paints website (Heat Reflective Paints, accessed 18/6/2010) provides some information about brands such as ASTEC, DuroBond, NuTech, ShieldCoat and SolaCoat. The website expresses disappointment in the way some of the paints and additives are marketed technically.

COMPARISONS WITH CONVENTIONAL PAINTS

INSULADD provide comparisons as seen in Figure 6 (INSULADD, accessed 16/6/2008). They show lower surface temperatures of INSULADD white paint compared with other paints and materials for Central Texas in August (Summer) with an ambient of 33 °C in clear sunlight. These tests clearly demonstrate the benefits of the white, heat reflective paint over the other alternatives.

In Figure 5, there is the reflectance comparison by ASTEC of a conventional black paint with their Energy Star Black (ASTEC, accessed 14/6/2010, p. 3). Whilst there are large infra-red reflectance gains at wavelengths over 1000 nm, it should be remembered from Figure 1 that there is a major part of the incident infra-red from sunlight between 700 nm and 1000 nm. A truly effective heat reflective black paint would rise sharply in reflectance to high values at wavelengths very close to 700 nm where it will have a greater effect.

A comparison of reflectances for a conventional and a heat reflective Off White paint from ASTEC data (ASTEC, accessed 16/6/2008) are shown here in Figure 7. This shows less of an advantage in infra-red reflectance for Energy Star paint over standard paint when compared with Figure 5 for a black colour. Between 90 and 95 percent of pigment in a standard off-white colour will be TiO_2 which already scatters strongly in

dirt collection. Similarly, if the paint is to be sprayed then it is preferable to spray the gloss paint wet to attain the smoothest surface possible that will not quickly capture dirt and dust. Two coats are necessary to ensure opacity at infra-red wavelengths.

If the application is critical, such as coatings over insulation around piping carrying refrigerated fluids, then optimal solar heat reflection can be attained with a heat reflective version of a pure white paint.

If architectural or aesthetic reasons eliminate the use of a pure white paint because of glare, then as light as possible coloured paint should be used. The paint should be heat reflective to ensure that as much infra-red as possible is reflected at the surface and reduce the heat load on buildings and pipework.

Diagrams:

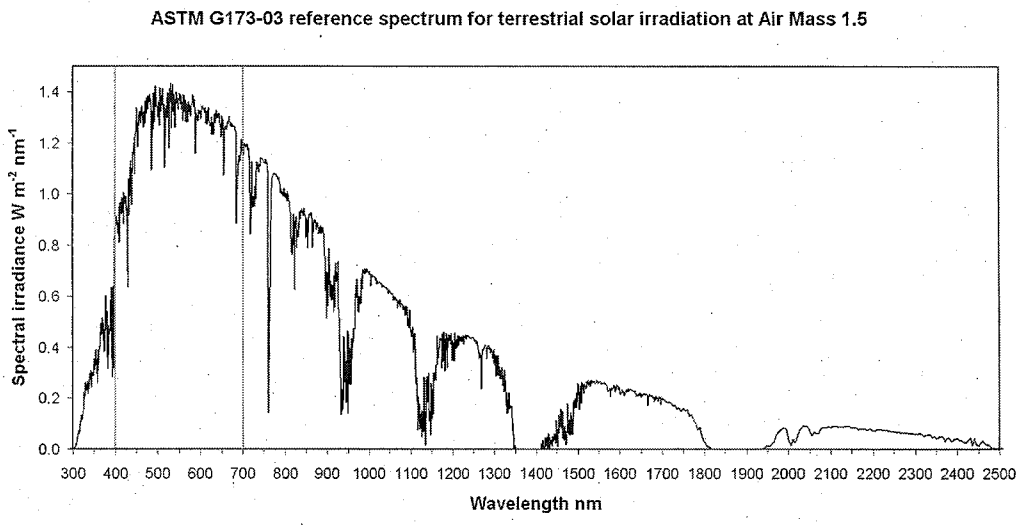

Figure 1 - Solar Radiation Spectrum at Sea level showing ultra violet (<400 nm), visible (400 – 700 nm) and infra-red (> 700 nm) components. There are absorption regions where water, oxygen and carbon dioxide in the atmosphere absorb some of the incident radiation. Data plotted from the ASTM G173-03 reference data for solar irradiance at Air Mass 1.5.

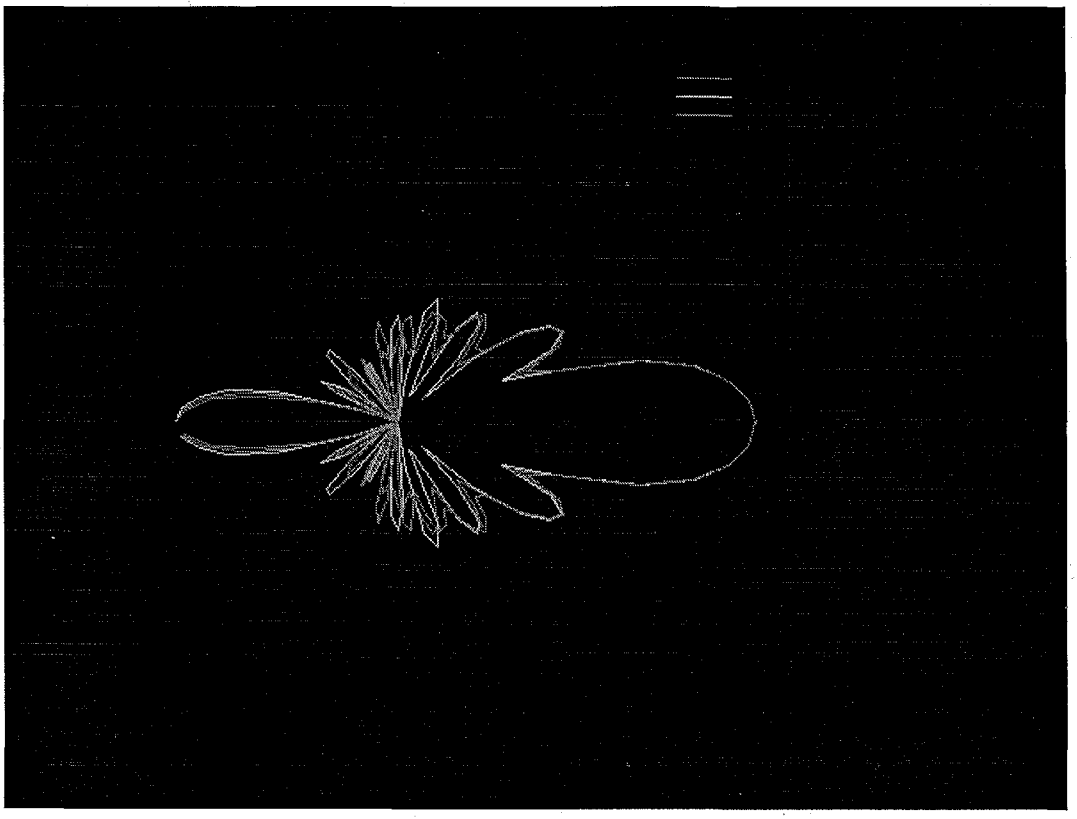

Figure 2 - Light scattering on a log scale from a 1 μm TiO_2 particle in paint, showing backscattering from calculations at http://omlc.ogi.edu/calc/mie_calc.html



Figure 3 - The highlighted milkiness surrounding the diver and beneath her entry point in the water is caused by Mie scattering of fine air bubbles causing reflection of ambient light. The medium has a refractive index of 1.3 and the bubbles a refractive index close to 1.0.

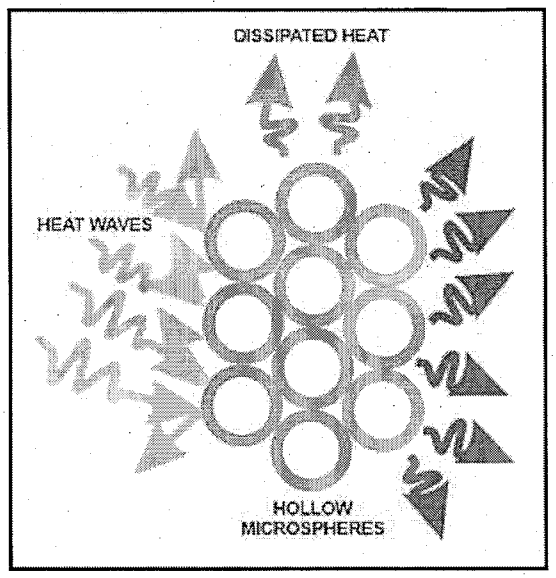

Figure 4 - This figure from INSULADD (INSULADD, accessed 10/6/2010) infers that there is no paint medium between the microspheres.

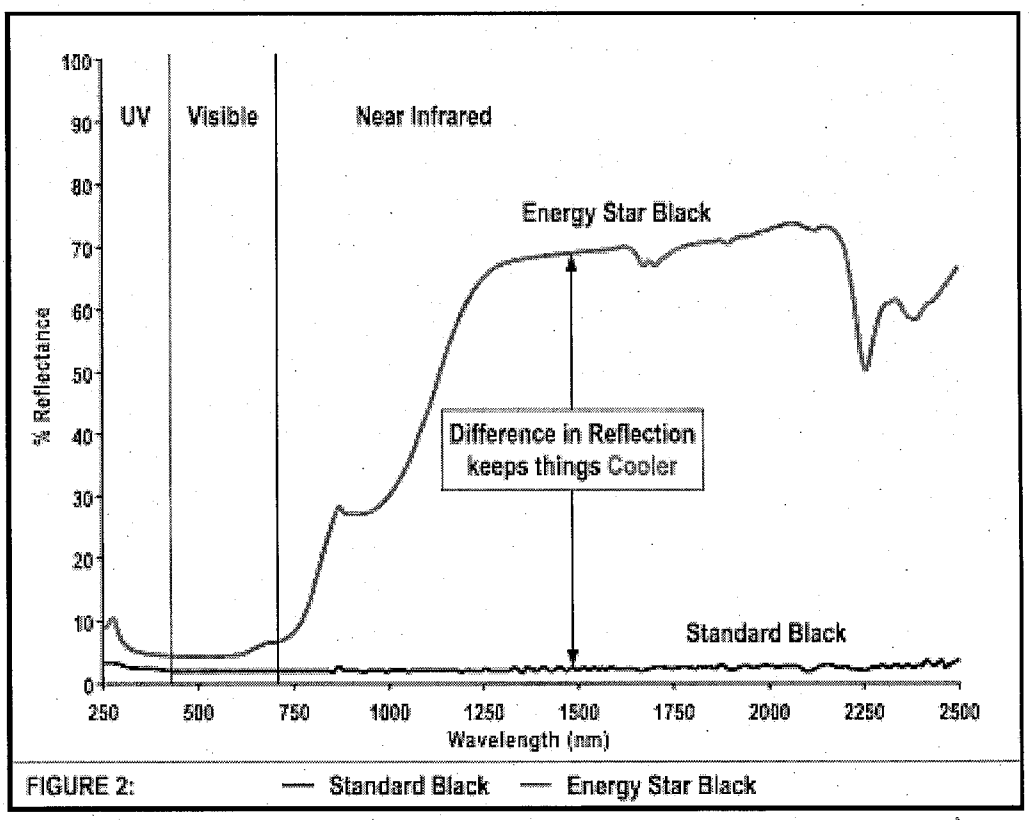

Figure 5 - ASTEC comparison of their heat reflective Energy Star Black with a standard black paint demonstrating substantially increased infra-red reflectance at wavelengths above 1000 nm (ASTEC, accessed 14/6/2010, p. 3)

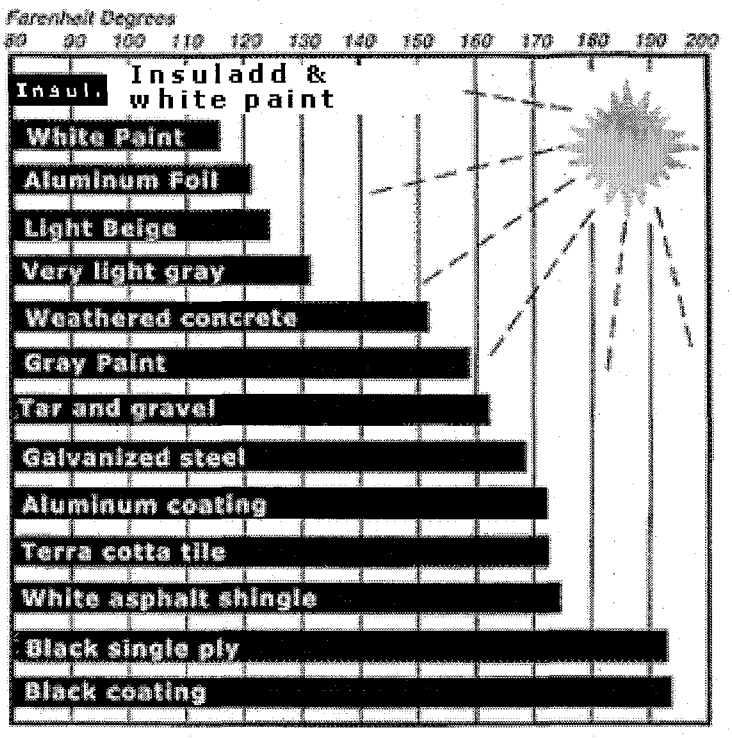

Figure 6 - Temperatures of coatings and other materials in sunlight conditions in Central Texas in August with an ambient of 90 °F (33 °C) and a clear sky.

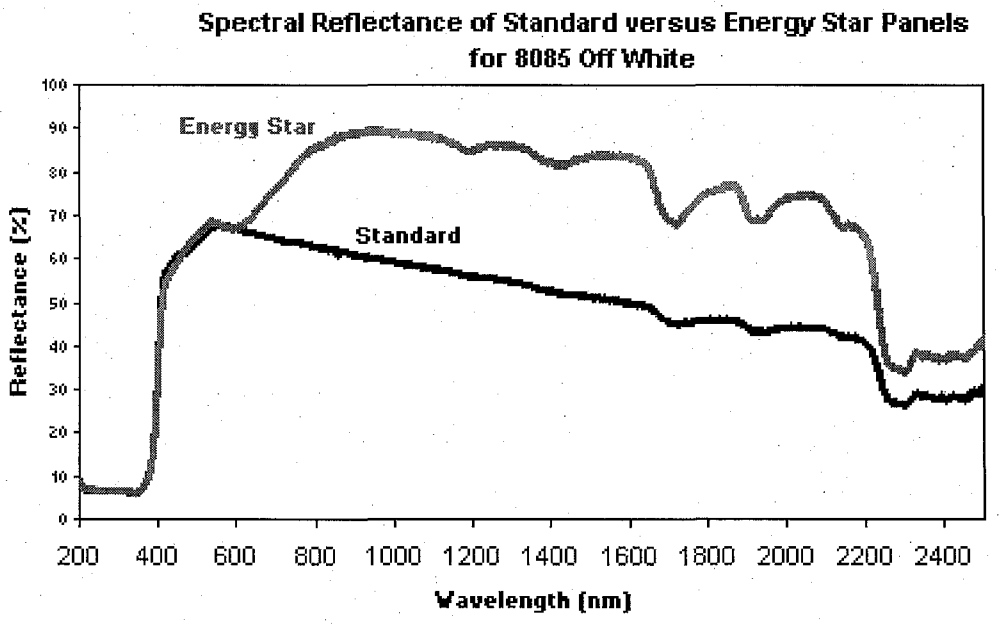

Figure 7 - ASTEC comparison of their heat reflective Energy Star Off White with a standard off white paint demonstrating substantially increased infra-red reflectance at wavelengths over 700 nm.

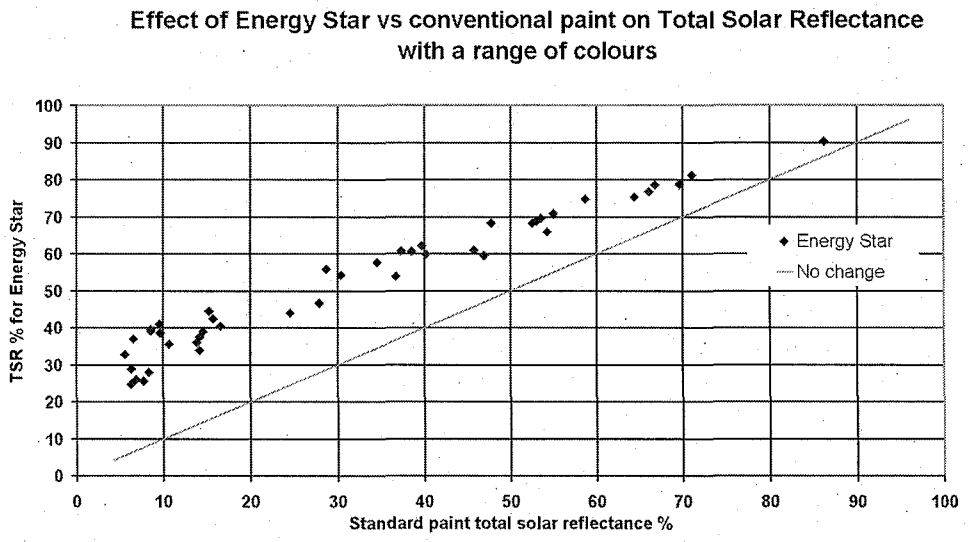

Figure 8 - Comparisons between heat reflective and conventional paints graphed from ASTEC data.

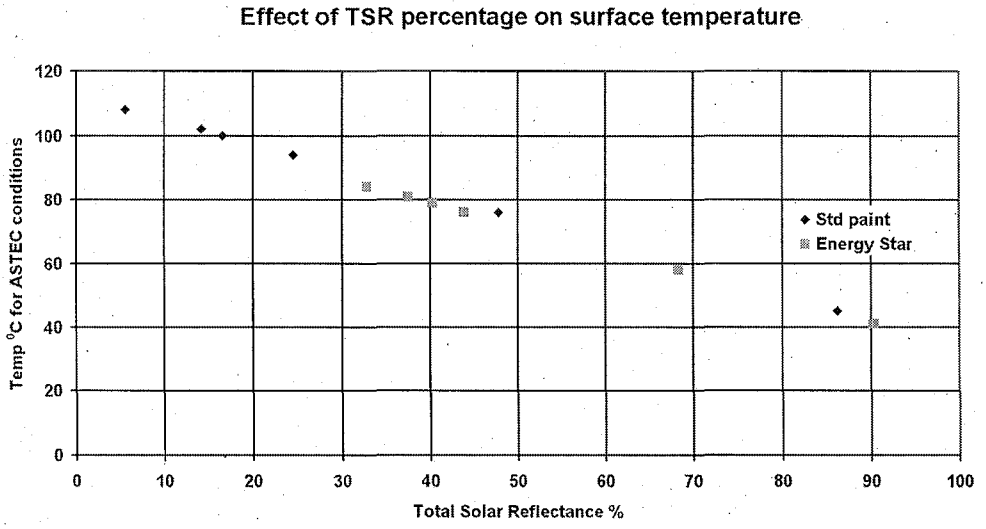

Figure 9 - Demonstrating the direct influence of TSR with various colours on the surface temperature encountered under the ASTEC experimental conditions and the relatively small effect of whether the paint was a heat reflective or a conventional one.

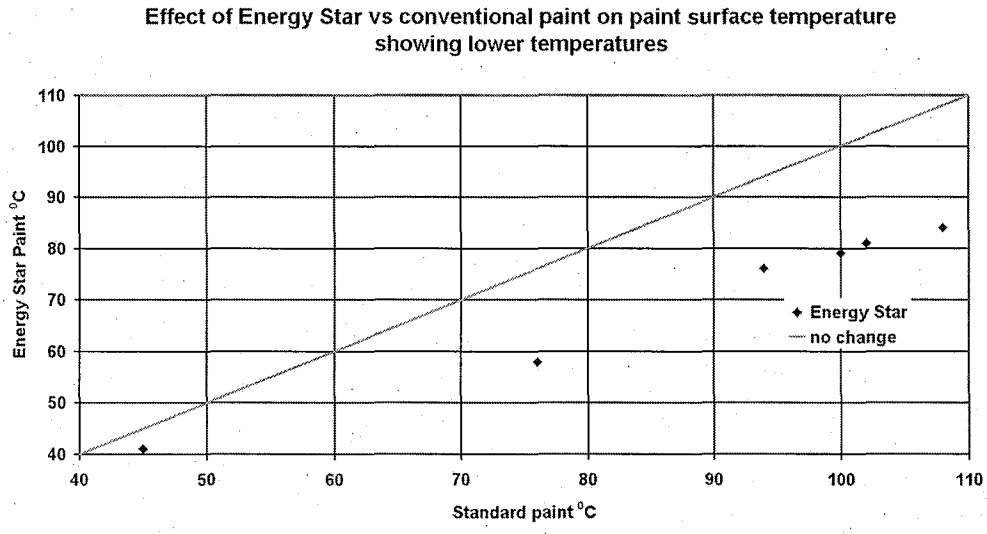

Figure 10 - Reductions in surface temperature for a range of colours with Energy Star paints as plotted from ASTEC data.

Table 1 - Acryloc comparison of surface temperatures with the heat reflective Roofcote products compared with Acryloc's standard products under infra-red lamps. The effects under sunlight would not be as good.

Colour	Cooler than CRC Equiv by
Arctic White	3°
Blue Ridge	16°
Brunswick Green	-
Bushland	
Charcoal	22°
Classic Cream	13°
Cottage Green	40°
Deep Ocean	15°
Dune	
Headland	15°
Ironstone	39°
Jasper	37°
Manor Red	19°
Night Sky	36°
Pale Eucalypt	
Paperbark	25°
Plantation	28°
Sandbank	29
Shale Grey	26°
Sienna Clay	14°
Stone	29°
Surfmist	
Wheat	31°
Wilderness	27°
Windspray	29°
Woodland Grey	17°

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BRIEF BIOGRAPHY OF PRESENTER

John Pockett has had a broad career mainly in industrial R&D, process/product improvements and data analysis across a range of industries, leading-edge technologies and working across engineering and scientific disciplines. He has worked in areas such as paint, medical equipment, electronics, ophthalmic, laser, printing, photovoltaics, electrophotography and biofuels. He has had practical experience in independent research. Innovations have led, amongst other things, to patented IP and IP utilised as Trade Secrets. He has been employed in organisations such as Dulux, Optische Industrie, Philips, SOLA Optical, Research Labs of Australia, Adelaide University, Uni. of SA, Flinders Uni, and carried out consultancy work in John Pockett & Associates. His original BSc in Physics and Maths was supplemented in recent years by a PhD in Materials Science (Polymer Chemistry) on a part-time/full-time basis whilst continuing with his consultancy work.

In the last three years he has also played a part-time role in University of South Australia's Sustainable Energy Centre as an Adjunct Senior Research Fellow working on projects, often along with other researchers and students. These projects include retrofitting vehicles to make them hybrids, phase change materials, roof insulation, radiative cooling and heat reflective paints.

He is on the Organising Committee for Chemeca2010, is currently Chair of the Joint Chemical Engineering Committee in SA, is on the SA Committee for the Australian Solar Energy Society, is a Chartered Chemist member of the Royal Australian Chemistry Institute and is a Fellow of the Australian Institute of Physics.