# Cool colored coatings for passive cooling of cities

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## ABSTRACT

The heat island effect is becoming increasingly more intense in urban areas causing thermal discomfort, increased energy demand and accelerating the formation of harmful smog. The mitigation of the heat island effect can be achieved by the use of cool materials. Cool materials are characterized by high solar reflectance and infrared emittance values. In the framework of this study, the performance of prototype cool colored coatings, developed at the National and Kapodistrian University of Athens, using near infrared reflective color pigments is reported, in comparison to color-matched, conventionally pigmented coatings. The solar spectral properties and the infrared emittance were measured and the surface temperature of the tested coatings applied on concrete tiles was monitored, using surface temperature sensors and a data logging system. The experimental results indicate significant success in developing cool colored coatings. It was found that all the coatings containing infrared reflective pigments have higher solar reflectance values and lower surface temperatures than those of the standard coatings. Cool colored coatings can be used on buildings (roofs and walls) and other surfaces of the urban environment or they can be used to manufacture other cool colored building materials. Furthermore, this paper presents the results of a modelling study, undertaken for the case of Athens, Greece, that attempts to asses the impact of large scale increases in surface albedo, resulting from the use of cool materials, on the ambient temperature. The results of this study can help to promote the adoption of high albedo measures (the use of cool materials) in building energy codes and urban planning regulations.

## 1. INTRODUCTION

Several techniques have been proposed for the mitigation of the heat island effect. Among them the use of cool materials has gained a lot of interest during the past few years. Cool materials are characterized by high solar reflectance and infrared emittance values. These two properties mainly affect the temperature of a surface (Bretz et al., 1997; Akbari et al., 1997; Rosenfeld et al., 1996). Increasing either reflectance and/or emittance lowers a surface' s temperature, which in turn decreases the heat penetrating into the building, if it is a surface of the building envelope, or contributes to decrease the temperature of the ambient air as heat convection intensity from a cooler surface is lower. There are a number of cool materials currently commercially available for buildings and other surfaces of the urban environment (e.g. cool surface coatings, reflective tiles, light colored marble and mosaic, concrete and conventional asphalt with white aggregate) but they are white or light coloured (Berdahl et al., 1997; Akbari et al., 2001; Doulos et al., 2004; Synnefa et al., 2005). However, there is a need for cool non-white products because in many cases the aesthetics of darker colors is preferred. Cool non-white coatings, absorb in the visible range, in order to appear having a specific colour, but they should be highly reflective in the near infrared part of the electromagnetic spectrum to maintain a high solar reflectance. This is very important considering the fact that about half of all solar power arrives as invisible near infrared radiation. Specialized, complex inorganic color pigments that are dark in color but have the ability to reflect strongly the near infrared (NIR) portion of the solar spectrum have been created by pigment manufacturers and they are used in order to develop cool colored coatings with higher solar reflectance compared to conventionally pigmented coatings (Ferro, Shepherd). Cool colored coatings can be applied on building envelopes and other surfaces of the urban environment as exterior finishes and paints or they can be used to manufacture building materials that reflect more sunlight than conventionally pigmented products. City scale application of cool materials will increase surface albedo. This means that surface temperatures will be lower as well as near surface air temperatures. In the framework of a research program supported by the California Energy Commission several engineering methods have been developed to apply cool coatings to roofing materials (clay tiles, concrete tiles, metal roofs and shingles). In general, the solar reflectance of commercially available roofing products has increased to 0.30-0.45 from 0.05 –0.25 for all materials except shingles whose solar reflectance exceeds 0.25. Furthermore, Kinouchi et al. have developed a new type of pavement that satisfies both high albedo and low brightness based on the application of an innovative paint coating on conventional asphalt pavement. The pigments and coating structure used are effective in achieving low reflectivity in the visible part of the spectrum (23%) and high near infrared reflectivity (86%). Field measurements for this type of pavement show that the maximum surface temperature of the paint coated asphalt pavement is about 15°C lower than that of the conventional one. Regarding the impact of large scale albedo changes to the ambient air temperature, Sailor (1995) showed by means of 3D meteorological simulations that increasing the albedo over downtown Los Angeles by an average 0.08 decreased summertime temperature by as much as 1.5°C. Furthermore, Taha (1997) found that increasing the albedo of the California' s South Coast Air Basin by 0.13, simulated reductions of averagely 2°C. This study aims to report the measured optical properties (solar spectral reflectance) and the thermal performance of 10 prototype cool colored coatings, developed at the National and Kapodistrian University of Athens using near infrared reflective color pigments in comparison to color-matched, conventionally pigmented coatings. Additionally, a simulation study was undertaken in order to asses the impact of large scale increase in albedo of Athens, on lowering the near surface air temperature.

## 2. EXPERIMENTAL MEASUREMENTS

Ten prototype cool colored coatings were created at the National and Kapodistrian University of Athens using special NIR reflective color pigments and were tested in comparison to color-matched, conventionally pigmented coatings. All the coatings tested are acryl-based coatings and they can be applied on building envelopes (roofs and walls) and other surfaces of the urban environment. The coatings were applied on white concrete pavement tiles. The tiles had a size of 40cm x 40cm. In order to study the optical properties and the thermal performance of the coatings the following parameters were measured: a) The surface temperature of the samples on a 24h basis. The basic experimental equipment consists of surface temperature sensors (thermocouples type K) connected to a data logging system. Instantaneous values were measured and saved on a computer hard disc every 10 minutes. The temperature sensors were placed on the center of the surface of each tile. b) The infrared emittance of the samples was also measured with the use of the Devices & Services emissometer model AE. This emittance device determines the total thermal emittance, in comparison with standard high and low emittance materials. c) The spectral reflectance of the samples was measured using UV/VIS/NIR spectrophotometer (Varian Carry 5000) fitted with a 150mm diameter, integrating sphere (Labsphere DRA 2500) that collects both specular and diffuse radiation. The reference standard reflectance material used for the measurement was a PTFE plate (Labsphere). During the experimental period, the ambient meteorological conditions were characterized by high temperatures, low relative humidity, low wind speeds and clear sky. The samples were placed on a horizontal platform, insulated from below in order to eliminate the heat transfer effects between the platform and the samples. The experimental procedure took place during the months of August to October of 2005.

## 3. ANALYSIS OF THE THERMAL PERFORMANCE AND OPTICAL PROPERTIES OF THE COATINGS

### *3.1 Solar spectral reflectance of the coatings*

Based on the results of the spectrophotometric measurements, the solar reflectance of each sample was calculated. The calculation was done by the weighted averaging method, using a standard solar spectrum as the weighting function. The spectrum employed is that suggested by ASTM (ASTM E903-96, ASTM G159-98).The values of solar reflectance for each sample are shown in Table 1. All the coatings containing infrared reflective pigments have solar reflectance values higher than those of the standard coatings. The highest difference in the solar reflectance was observed between cool black (2) coating (SR=27%) and standard black (2) (SR=5%). The %increase of solar reflectance was 440%. In contrast, the smaller difference in the solar reflectance was observed between cool light blue coating (SR=42%) and standard light blue (SR=40%), with a %increase of solar reflectance of only 5%. In general, the increase in solar reflectance varies with the color of the coating but it appears to be higher for dark colors.

Spectral reflectance measurements showed that the reflectance curves for each standard and its corresponding cool coating coincide in the visible range, indicating that the coatings are color-matched, they appear to have the same color. Furthermore, almost all of the standard coatings exhibit low or modest reflectance in the NIR range, while the cool colored coatings exhibit a more selective absorption band, reflecting significantly the NIR radiation. Figure 1, depicts the measured spectral reflectance for cool and standard black (2). The standard black coating shows strong absorption over the entire solar spectrum. Cool black (2) is spectrally selective having a NIR reflectance significantly higher then the standard black coating.

Table 1: Solar reflectance (SR) of cool and colored matched standard coatings and % increase in SR between them.

| Colour | Solar Reflectance (%) | | % Increase |
|---|---|---|---|
| | Cool | Standard | $SR_{(cool\text{-}stand)}$ |
| Orange | 63 | 53 | 19 |
| Light blue | 42 | 40 | 5 |
| Blue | 33 | 18 | 83 |
| Green | 27 | 20 | 35 |
| Black (1) | 12 | 6 | 100 |
| Anthracite | 26 | 7 | 271 |
| Brown | 34 | 23 | 48 |
| Choc. brown | 27 | 9 | 200 |
| Light brown | 36 | 22 | 64 |
| Black (2) | 27 | 5 | 440 |

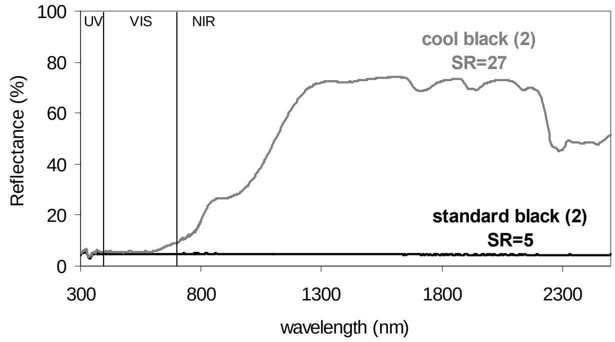


Figure 1: Spectral reflectance of the cool and standard colour matched coatings.

### *3.2 Evaluation of the thermal performance of the coatings*

During the day, it was found all the cool colored coatings had surface temperatures lower than the colored matched standard ones (Fig. 2).

The best performing cool coatings were black (2), chocolate brown, blue and anthracite that maintained a difference in mean daily surface temperature from their standard color matched coatings by 5.2, 4.7, 4.7 and 2.8°C respectively, for the month of August. The highest temperature difference was observed between cool and standard black (2) and was equal to 10.2°C, corresponding to a difference in their solar reflectance of 22. The lowest temperature difference was observed between cool and standard green (2) and was equal to 1.6°C(for Au-

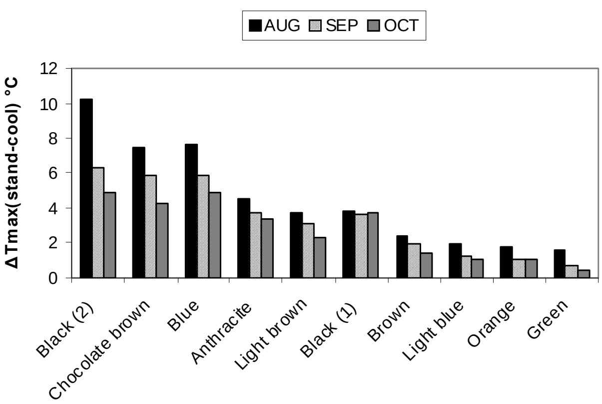


Figure 2: Difference between the maximum surface temperature of the cool and its colored matched standard coating during daytime.

gust), corresponding to a difference in their solar reflectance of 7.

This temperature difference between the cool and the standard coatings can easily be explained. If a coating appears for example black, this means that it must absorb in the entire range of the visible spectrum. This light energy that is absorbed, it is converted to heat energy, resulting in the raise of the surface temperature of the sample. The same applies for the cool and standard black coatings that both absorb strongly in the visible range (Fig. 1). In the near infrared range, the standard black coating, continues to show very low reflectance, absorbing not only all the visible light that enters its surface but also the infrared part of solar energy. In contrast, a coating containing infrared reflective pigments, exhibits a more selective absorption band (like the cool black). Therefore, although it still absorbs all of the visible wavelengths, a large part of the near infrared radiation is reflected rather than absorbed. If we consider the fact that almost half of the solar energy that arrives to earth is infrared, it becomes evident that the black coating that absorbs this part will become hotter than the coating that reflects it.

The temperature difference between the cool and standard coatings decreases from August to October (Fig. 2) as the monthly average daily global solar radiation decreases too, and the impact of the infrared reflecting pigments in the coatings becomes less evident. It was found that the coatings with the higher values of solar reflectance demonstrated the lower surface temperatures. A strong correlation ($R^2$=0.92) was found between the maximum daily surface temperature and the solar reflectance of the samples. We can therefore assume that the main factor affecting the thermal performance of the samples during the day is their solar reflectance.

During the night when there is no solar radiation, the surface temperature of the samples was found to be quite uniform due to the fact that all the coatings have an emissivity of about 0.88. However, cool colored coatings remain cooler (by 0.1 to 1.6°C) than the standard color matched coatings, probably because they have absorbed smaller amounts of solar radiation during the day. Small variations in the measured emissivity explain the variations in the night surface temperature.

## 4. AIR TEMPERATURE IMPACT OF INCREASED URBAN ALBEDO

A mesoscale modeling study has been carried out aiming to evaluate the impact of large scale increases of urban albedo on surface and near surface air temperatures during the summer period in Athens, Greece, a densely populated city. The numerical simulations were performed using the ‘urbanized’ version of the non-hydrostatic PSU/NCAR Mesoscale Model (MM5, version V3-6-1), (Dandou et al, 2005). The whole process was supplemented by detailed information on land use cover, derived from satellite image analysis (spatial resolution 30 m). Four nested domains were simulated, using two-way nesting. The simulated domains covered the extended areas of Europe, Greece, Attica peninsula and the city of Athens respectively. The spatial resolution for the innermost nested domain (the city of Athens) was 0.67 x 0.67 $Km^2$. Simulations have been performed for a typical summer day, the 15$^{th}$ August 2005. Two scenarios have been investigated. The base case scenario has considered a building structure albedo equal to 0.18, while the alternative scenario has considered an albedo of building structures close to 0.63. Such an albedo can be achieved using cool and cool colored materials described previously. It was found that large-scale increases in albedo have an impact on air temperatures of the city. Simulation results have shown that increasing the albedo of building structures by 0.45, decreases the ambient temperature (Fig. 3). This decrease, at the center of the city and at 2m height at 15:00 LST, varies between 0.8 to 1.6° C.

## 5. CONCLUSIONS

The mitigation of the heat island effect can be achieved by decreasing the thermal gains in the urban environment, and in particular the amount of the absorbed solar radiation. This can be done by increasing the albedo of cities using materials for buildings and the urban fabric that have high solar reflectance values. In order to meet the building market’s aesthetic preferences, cool non-white materials are needed. The results of this study indicate significant success in developing cool colored coatings that have the same visible reflectance with the standard coatings,

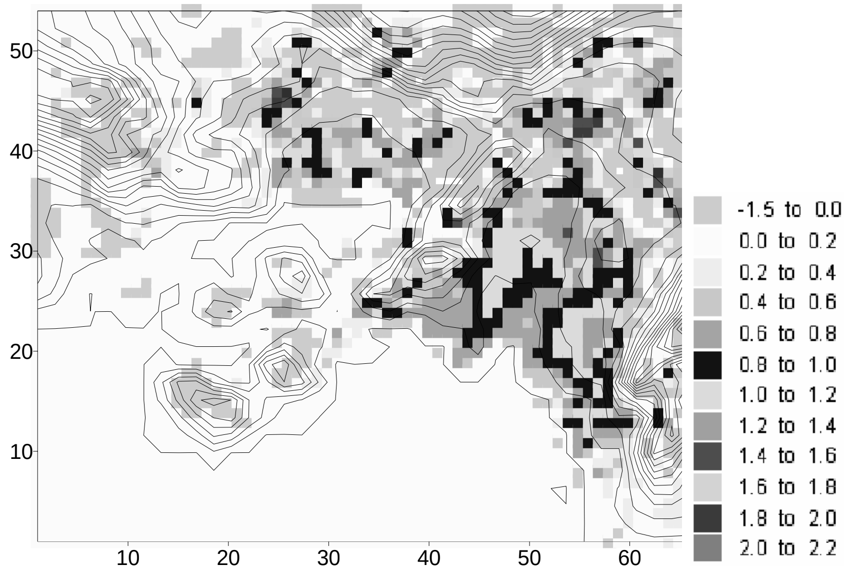

Figure 3: Decrease in air temperature at 3p.m on August 15 resulting from the urban albedo increase.

appearing to have the same colour, but they exhibit a more selective absorption band in the infrared part of the spectrum, reflecting large parts of the solar energy that arrives as infrared radiation rather than absorbing it. This results to lower surface temperatures for all the cool colored coatings. The maximum difference between the solar reflectance of a cool and standard colored coating was found to be 22 with a corresponding temperature difference of 10.2°C, for summer conditions. Furthermore it was demonstrated by means of simulation that using cool materials at city scale lowers air temperatures. Increasing the albedo of building structures by a feasible 0.45, can decrease air temperature by 1.6°C.

The use of cool colored coatings is not limited to their direct application on building envelopes, resulting to the reduction of surface temperatures and leading to lower cooling energy consumption for air-conditioned buildings and increased thermal comfort for unconditioned building; they can also be used to manufacture other cool colored building and paving materials. The use of cool colored coatings is a passive solution that combines energy efficiency and the aesthetic appeal of the products.

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