DEVELOPMENT AND ANALYSIS OF INORGANIC COATING FOR ENERGY SAVING FOR BUILDINGS

Konstantinos Gobakis[1], Dionysia Kolokotsa[1], Noni Maravelaki-Kalaitzaki[2], Stratos Lionakis[2], Vasilios Perdikatsis[3], Matheos Santamouris[4]

1 School of Environmental Engineering, Technical University of Crete Kounoudipiana Crete, Greece

2 School of Architecture, Technical University of Crete Kounoudipiana Crete, Greece

3 School of Mineral Resources Engineering, Technical University of Crete Kounoudipiana Crete, Greece

4 Physics Department Section of Applied Physics, Physics Department National and Kapodistrian University of Athens Build. Physics 5 15784 Athens, Greece

ABSTRACT

Buildings account for 40% of Europe's energy use and a third of its greenhouse gas emissions. Building materials currently used in the construction of building have low solar reflectance, leading to an increase of surface temperature of the building. The aim of the present study is to develop various inorganic and colour change coatings for increasing the solar reflectance of buildings. A series of inorganic coatings are examined and tested. Their thermal properties are estimated by infrared thermography, surface temperature measurements, emissometer and chemical properties by X-ray diffraction and Fourier transform infrared spectroscopy.

KEYWORDS

Cool materials, inorganic, thermochromic

Heat island is the more documented climatic change phenomenon (Cartalis C. 2001). Important research has been carried out to document its strength and its influence on the urban climate (Santamouris 2007; Akbari et al. 1999). Heat island intensity in hot climates may rise up to 10^{o}C (Livada et al. 2002; Mihalakakou et al. 2002) , resulting in increased discomfort, higher pollution levels while it has a serious impact on the cooling energy consumption of buildings (Hassid et al. 2000). Increased urban temperatures, exacerbate the peak electricity demand for cooling and decrease the efficiency of air conditioners, while it reduces considerably the cooling potential of natural and night ventilation techniques (Geros V. 2005) and increases the urban ecological footprint.

Another significant effort towards energy conservation for buildings and urban structures is the research for cool materials (e.g. reflecting tiles, membranes, colors) and coatings as a passive cooling technique (Synnefa et al. 2007; Oke et al. 1991; Zinzi 2010). Those materials target to minimize the surface temperature in roofs, masonries and pavements through the increase of solar reflectance and infrared emittance(Asaeda et al. 1996). Coatings with specific optical properties, such as increased reflectance and/or emittance resulting in lower surface temperatures are developed and tested. Even though the tested coatings range from cool materials, thermochromic, phase change materials, etc. (Bretz & Akbari 1997; Karlessi et al. 2009). Nevertheless, corrosion can effectively diminish their performance. This issue intensifies the need for resistant materials. Based on the above, the study of lime renders', mortars' and natural paints' thermo-physical properties are of a major importance. Although various studies can be found (Veiga et al. 2009; Hernández-Olivares & Mayor-Lobo 2011) that quantify their density, thermal conductivity, etc., there is a significant lack of information concerning their optical properties and their contribution to energy conservation. While the optical properties of common colorants and materials for the built environment (Doulos et al. 2004; Papadopoulos et al. 2008) are studied in the past, the natural materials and coatings' optical characteristics and their potential role as a passive solar technique is still under study.

To this end, the aim of the present work is to examine the performance of mineral-based coatings as a passive solar technique that contributes to buildings' energy efficiency. This is achieved by investigating the optical properties and thermal behavior of these coatings in an attempt to lower the surface temperature of the built environment thus increasing energy efficiency. Mortars and plasters consisting of lime and/or natural hydraulic lime with pozzolanic additions as binders, inorganic additive such as calcite powder and aggregates of carbonate nature are designed and tested. The surface temperature of the developed samples is measured using infrared thermography and surface thermocouples. A series of measurements is also performed for the evaluation of the solar reflectance and infrared emittance of the samples. The energy efficiency of the developed samples is finally investigated using simulation techniques.

1 MATERIALS AND METHODS

1.1 Design concepts and technical specifications of coatings

The studied plasters are commonly used either in the building construction sector or in the restoration of historic buildings. The aim of the present section is to describe the development procedure and technical specifications of the various mineral based samples tested.

The approach of making the samples is similar to that is used in the real world with some modifications in order to shorten the developing time. The development of the samples is separated into two different stages. The first stage of process was the preparation of the substrate. Sample carriers were constructed with dimensions 9cm x 9cm x 3cm from sheet metal with thickness of 0.5mm. The substrate was created inside the carriers with a thickness of 2.7 – 2.8 cm using 28% Portland cement, 56% limestone and 16% water (Figure). On the top, a large amount of cotton was placed. The cotton was regular moistened with water to ensure proper curing of cement for a five days period. The second stage of the proses was the development of various coactions on top of the substrate which will be analytical presented later.

Figure 1 Sample carrier with substrate

1.2 Mineral-based coating binders lime renders and paintings

1.2.1 Mineral based binders

The binders used are made of natural hydraulic lime (NHL), produced by calcining agillaceous or siliceous lime stones at temperatures of 900 - 1200 °C. These temperatures are higher than those typically used for the production of quick lime (CaO), typically around 1000 °C, but much lower than those used to produce cement (typically around 1400 °C). Natural hydraulic lime conforming to EN459 as a moderately hydraulic lime, is typically used for repointing/rendering and building works on most masonry types. These limes have become increasingly popular over the last decade due to their superiority in strength and weathering resistance compared to fat limes. Pozzolan or pozzolanic materials can react with calcium hydroxide to form hydraulic compounds acting as binders, which enhance the strength gain of hydrated, hydraulic and NHL mortars. In particular, pozzolan additions to a lime arc indicated by the letter Z following the lime designation e.g. NHL-3.5Z (BS EN 459-1:2001).

The calcined temperature of the raw materials of NHL is much lower than the required for the cement. Therefore, NHL can be considered as more environmentally-friendly hydraulic binder, because of the lower energy required to be produced comparing to the Ordinary Portlant Cement (OPC) and other cements.

1.2.2 Marble powders

Two different white marble powders were used on this experiment. The first one is a dolomite marble powder (DMP) (Ganguly 2010) originated from Kavala, Greece. The grading is following the standard EN13139 with maximum particle size of 250μm. X-Ray Diffraction (XRD) was performed for the verification of its composition ().

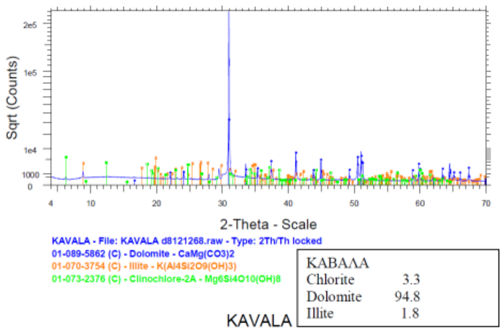

Figure 2 XRD dolomite marble powder

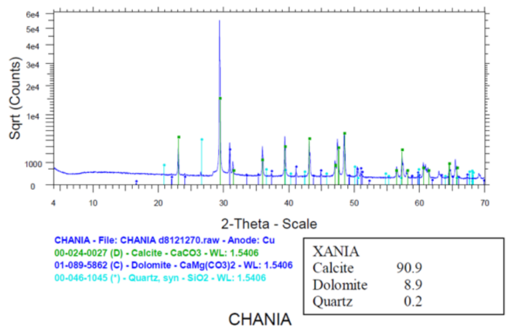

Figure 3 XRD limestone marble powder

The second is a limestone marble powered (LMP) originated from Chania, Greece. The grading is following the standard EN13139 with maximum particle size of 250μm. X-Ray Diffraction (XRD) was also done for the second marble powder (

Figure).

Among the specific characteristics of these renders it can be mentioned the high water permeability and resistance to UV radiation, weathering parameters and fungi's growth.. All these properties establish the above mentioned lime renders as appropriate finishing layers for masonry applications

1.2.3 Glass beads

The glass beads (GB) are predominantly used in road markings and have the ability to reflect incident radiation. They are made of SiO_2 (71-73%), Na_2O (13-15%), MgO (3-5%),CaO (8-10%), Al_2O_3 (0.5-2%) other (<2%) with a refractive index of 1.5 to 1.55, diameter of 180 – 850μm and roundness >80% following the EN 1424 standard. This sample was not tested by XRD. Because glass is amorphous and due to the fact that was accompanied by certificate by the manufacturer.

Figure 4 Glass beads

1.2.4 Inorganic thermochromic pigment

Thermochromic is called the chemical whose colour depends depending on the ambient temperature. Following literature survey inorganic compounds were chosen for the specific research. The chemical competition of this compound is $(Et_2NH_2)_2CuCl_4$. The compound is showing a vivid green colour at a low temperature and a bright yellow colour in relatively high ambient temperatures (Figure 5). The pigment's composition was verified using XRD. Using the crystal structure of the pigment, a simulated pattern were produced and compared with the experimental data.

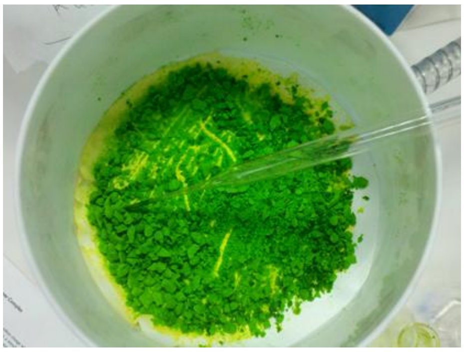

Figure 5 Thermochromic pigment in ambient temperature

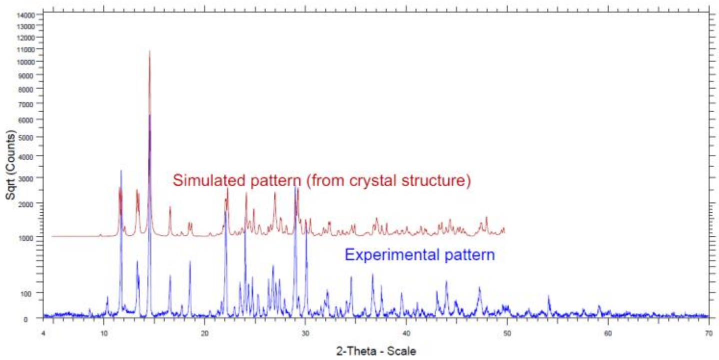

Figure 6 XRD of thermochromic pigment

1.3 Creation of samples

The sample names and composition are tabulated in Table 1. All the samples were cured for one month in stable humidity and temperature conditions (RH = 50 ± 5% and T = 22 ± 2^{o}C). A smooth and even surface was achieved for all samples with sanding proses (Figure 7). The thermochromic pigment was applied by a water solution (**Error! Reference source not found.**7).

Figure 7 Examined samples at the experimental site

Table 1: Composition, codenames of the studied samples.

Sample Code	Finishing	Ratio per volume	Type	Group
WCM-DMP	WCM/L/DMP	1/1/2	Render	1
WCM-LMP	WCM/L/LMP	1/1/2		
NHL-DMP	NHL/L/DMP	1/1/2		
NHL -LMP	NHL/L/LMP	1/1/2		
NHL -LMP-GB	NHL/L/LMP/GB	1/1/1.8/0.2		2
NHL -DMP-GB	NHL/L/DMP/GB	1/1/1.8/0.2		
P-TC	P	1	Paint	3

NHL, natural hydraulic lime NHL with pozzolanic additives; P, plaster; WCM, white Portland cement; L, hydrated lime; W, water.

Figure 8 Preparing thermochromic sample

2 EXPERIMENTAL PROCEDURE

2.1 Methodology and instrumentation

The analysis of the coatings' optical and thermal characteristics is divided into four phases:

1. K-type surface temperature thermocouples arc then used to measure the various samples surface temperature.
2. The solar reflectance and infrared emittance arc measured using a Cary 5000 spectrophotometer with integrating sphere and
3. Devices and Services emissometer.

The surface mounted thermocouples arc characterized by:

- Resolution: -200 to +200 (0.1 °C).
- Operating temperature and humidity: 0-50 °C and 0- 80%.
- Accuracy: -200 °C to 200 °C (±2% reading +1 °C)

The surface mounted K type thermocouples include an embedded thin insulation layer by silicon rubber to avoid the solar radiation influence. A small amount of thermal paste was placed between the K type thermocouple and the sample surface. The solar reflectance and infrared emittance arc measured using a Cary 5000 spectrophotometer with integrating sphere and a Devices and Services emissometer respectively.

3 RESULTS AND DISCUSSION

3.1 Results of surface temperatures measured using K type thermocouples

A series of surface measurements are performed using the K-type thermocouples. Due to limited number of data loggers the surface temperature measurements took place during different days of summer 2013. In order to be able to compare the results, the difference between the surface temperature of the samples and the air temperature is calculated and utilized. Also for competition reasons a Portland cement substrate were present on all measurements and is plotted on all figures. The results of the 1st Group are depicted in Figure 9. The samples of the 1st Group with the lowest surface temperature are NHL-DMP followed by WCM-DMP with a difference of 2.5°C from the heist surface temperature differences witch was recorded for WCM-LMP. Also the lowest average temperature differences were observed by NHL-DMP followed by WCM-DMP with a difference of almost 1°C witch was recorded for WCM-LMP.

The surface temperature differences for the 2nd Group are depicted on Figure 10. Regarding this group glass, beads were inserted as part of the composition. The NHL – DMP-GB had better performance than NLG-LMP-GB. Also NHL-DMP-GB had the lowest temperature of all the samples that were tested.

The surface temperature differences for the 3rd Group are depicted on Figure 11 Surface temperature measurement of the 3st Group The P-TC demonstrated lower temperature compared to the plaster. Also due to the very calm summer in the experiment location there was not possible the turning temperature to be reached.

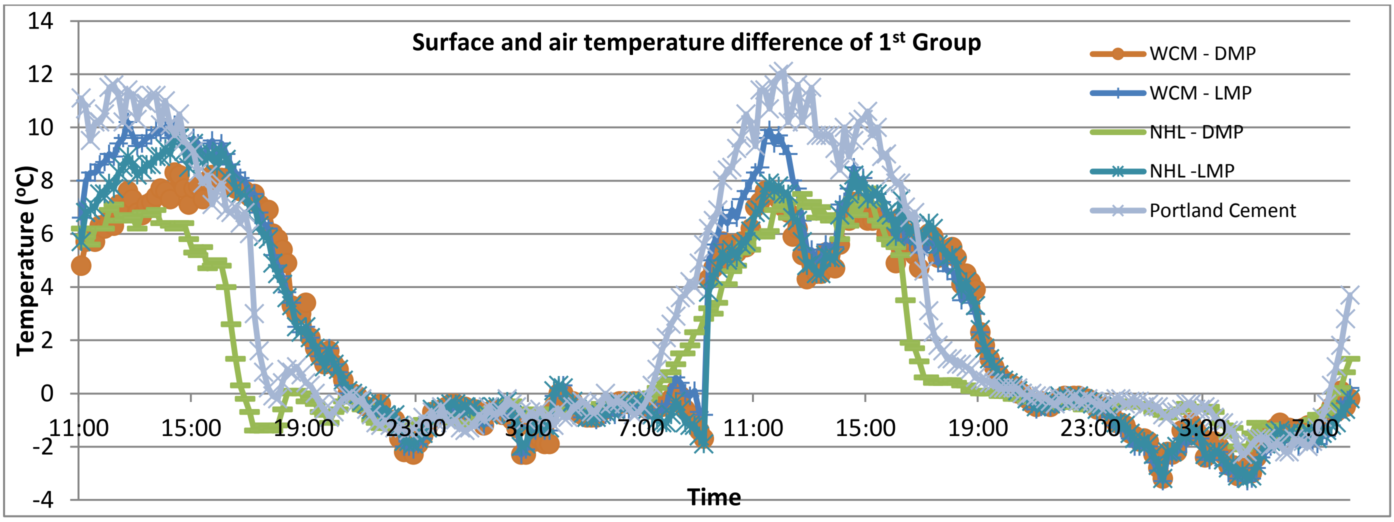

Figure 9 Surface temperature measurement of the 1st Group

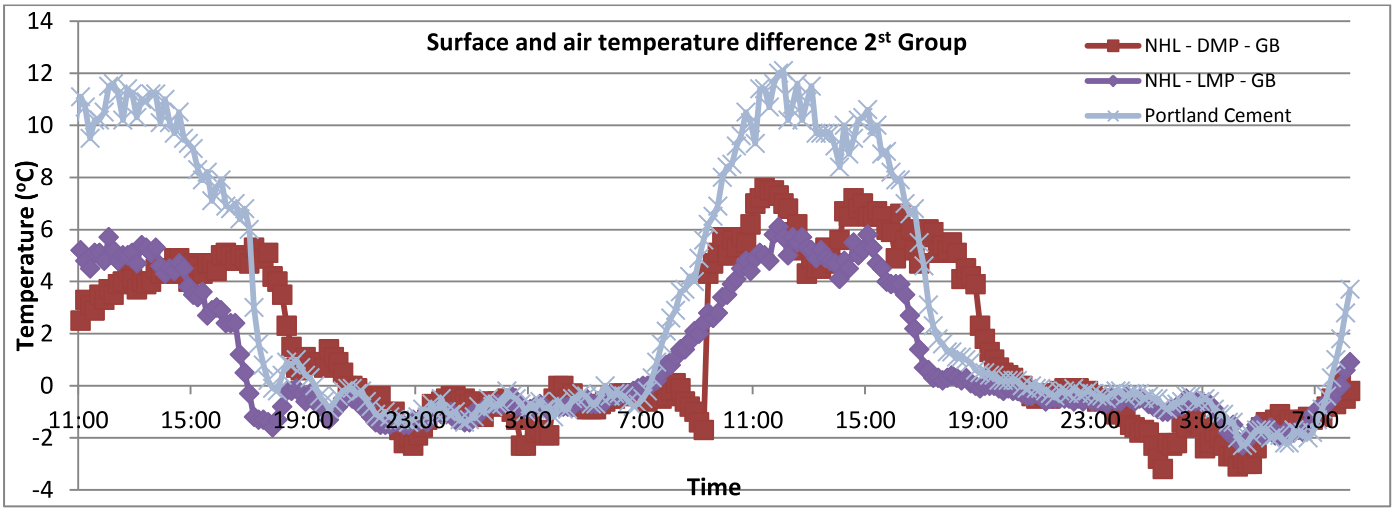

Figure 10 Surface temperature measurement of the 2st Group

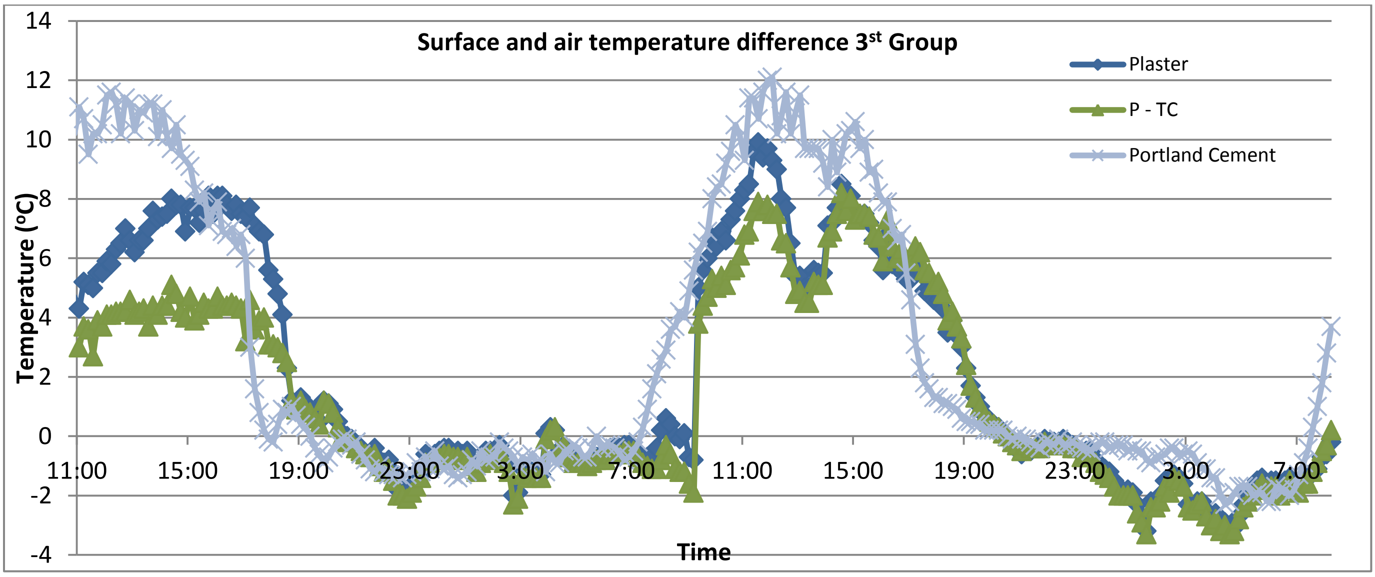

Figure 11 Surface temperature measurement of the 3st Group

3.2 Experimental results of the solar reflectance and infrared emittance

In this specific section the optical properties i.e. the solar reflectance and infrared emittance of the samples are measured. The sola reflectance results for the first, second and third group are depicted in Figure 12 and Figure 13. The total, infrared (IR), ultraviolet (UV), visible (VIS) solar reflectance, as well as infrared emittance are also tabulated in Table 2. The results for all samples show increased SR_{IR} which is in accordance with the surface temperature measurements.

The samples with increased solar reflectance and infrared emittance are with white cement. The additional of glass beads give a small increase on solar reflectance. The addtition of the thermochromic compound did not change the solar reflectivity of the plaster.

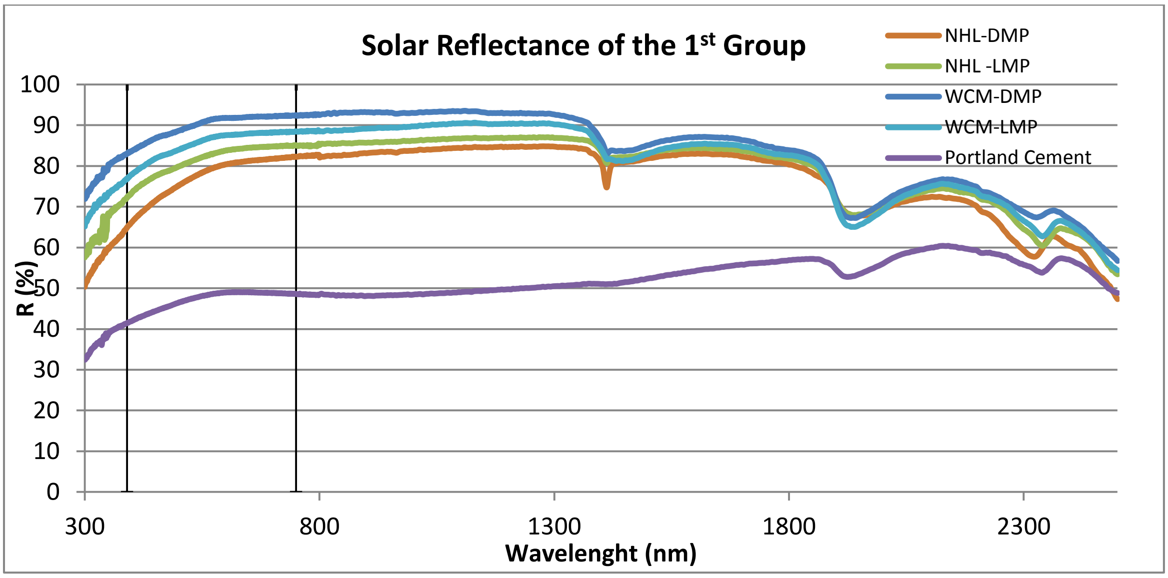

Figure 12 Solar Reflectance of the 1st Group

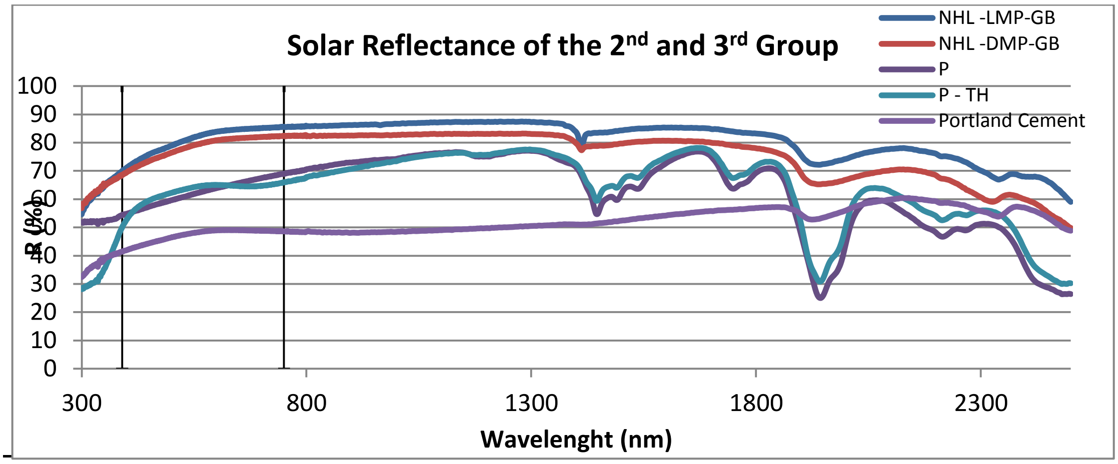

Figure 13 Solar Reflectance of the 2nd and 3rd Group

Table 2 Solar reflectance and infrared emittance of the various samples.

Sample Name	SR (%)	SR_{IR} (%)	SR_{VIS} (%)	SR_{UV} (%)	E (%)
WCM-DMP	89	90	90	78	0.83
WCM-LMP	86	86	85	71	0.81
NHL-LMP	82	84	81	64	0.88
NHL–DMP	79	81	77	57	0.88
NHL-LMP-GB	83	85	81	62	0.88
NHL-DMP-GB	80	81	78	63	0.85
P	66	70	62	52	0.85
P+TH	66	69	63	34	0.87
Portland Cement	49	50	47	37	0.78

4 CONCLUSIONS

The present study examined the thermal and optical properties, of a series of mineral based coatings. By examining the overall experimental results, the samples with dolomic marble powder where with natural hydraulic lime with pozzolanic additions. The addition of glass beads improved the overall performance of the sample. Therefore, the use of such coatings can be included in hot climates' construction due to their thermal performance, UV behavior and chemical composition.

The first experiments with the inorganic thermochromic pigment were very promising. Next the stability of long term exposure to solar radiation must be examined.

5 ACKNOWLEDGEMENTS

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