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On the Impact of Highly Reflective Materials on Thermal Comfort and Energy Efficiency

Elisavet Tsekeri **Angeliki Mavrigiannaki** **Konstantinos Gobakis, PhD**

Dimitrios Xilas **Dionysia Kolokotsa, PhD** *ASHRAE Member* **Maria Kolokotroni, PhD, CEng** *ASHRAE Member*

Francisco José Sánchez de la Flor, DrEng

ABSTRACT

The materials that compose the built environment have a key role in the resulting energy demand since their thermal properties affect the heat transfer processes. The use of cool materials aims at increasing the albedo of the urban surfaces and decreasing the heat absorbed by them. Cool materials can decrease roof temperatures, reduce energy needs for cooling and improve indoor comfort for spaces that are not air conditioned. Two new cool materials have been developed to be installed on the roof of two buildings in Cadiz, Spain and London; these are demonstration buildings of the H2020 project ReCO2ST which focuses on the NZEB retrofit of residential buildings with improved environmental quality and cost of installation. For Cadiz, a two-component acryl-epoxy hybrid water base coating was developed and for London a PVC roofing membrane with TiO2. Open Studio and Energy Plus were used to model and simulate the current situation as well as the scenario with the proposed cool materials. In Cadiz, the application of cool materials on the roof and on the south-east wall showed that a substantial reduction can be achieved in cooling needs by 30% leading to better thermal comfort. In London, simulation of the proposed cool material applied on the top of the roof, showed a significant effect in air room temperature and surface temperature reduction during a summer midday.

INTRODUCTION

The increase of greenhouse gas emissions and the consequent increase of atmospheric temperature are directly linked to the global warming phenomenon (Saber and Maref 2019). Climate change has a significant impact on the appearance of the effect of Urban Heat Island (UHI). UHI is an environmental problem, experienced in urban areas, that is characterized by the overall increase of temperature in urban areas, comparing with the surrounding rural areas (M. Santamouris 2015; Mat Santamouris and Kolokotsa 2016).

The energy consumption in buildings is affected by the local climate change, increasing the concentration of local pollutants while indoor and outdoor thermal comfort is aggravated and health problems are intensified (Sakka et al. 2012). Therefore, mitigating the heat island is the key to achieve sustainability in a city, by improving the urban microclimate (Gaitani et al. 2011). In order to balance the UHI, main mitigation techniques are the use of vegetation and application of new promising technologies; namely cool materials, aiming at increasing the albedo in the cities (M. Santamouris 2014).

DEFINITION AND ASSESSMENT OF COOL MATERIALS

Cool material, is a material which is characterized by combining high solar reflectance (SR) and high infrared emittance (IE). SR is the capability of a textured surface to reflect solar radiation over the solar spectrum, including the direct and the diffuse component. Having also high infrared emittance, a cool material is able to re-radiate previously absorbed heat. As a result, the

Elisavet Tsekeri is a PhD student in Technical University of Crete, **Angeliki Mavrigiannaki** is a research fellow in Technical University of Crete, **Konstantinos Gobakis** is a research fellow in Technical University of Crete, **Dimitrios Xilas** is a research fellow in Technical University of Crete, **Dionysia Kolokotsa** is an Associate professor in Technical University of Crete, **Maria Kolokotroni** is a professor in Brunel University, London, **Francisco José Sánchez de la Flor** is an Assistant professor in University of Cadiz, Spain

solar heat gain of buildings can be reduced by applying cool materials (Akbari, Konopacki, and Pomerantz 1999).
The Solar Reflectance Index (SRI) incorporates the IE and SR in a single value. According to ASTM E1980-01 "Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces", SRI quantifies how hot a flat surface would get relative to a standard black (SR=0.05, IE=0.9) and a standard white surface (SR=0.80, IE=0.90). The calculation of this index is based on a set of equations (ASTM 1980E-01) that require measured values of SR and IE for a specific environment. There is a big variety of studies, focusing on the application of these materials with high reflectivity, such as the cool pavement technology and the cooling coatings, in hot and sunny climates, throughout the world (Qu et al. 2019). The application of cool roof technologies has resulted into significant benefits for climate and serious reduction of UHI (Fintikakis et al. 2011; Gaitani et al. 2011). More specific, as highlighted by many studies, the benefits are the decrease of ambient temperature, the decrease of peak electricity demand almost 10% to 40%, the improvement of occupants' thermal comfort and the reduction of UHI, having a decrease in CO_2 emissions and an increase in the durability of materials (Baniassadi, Sailor, and Ban- Weiss 2019; Fang et al. 2019; Synnefa et al. 2008).
However, aging is a substantial aspect for the selection of a cool material. Aging is influenced by the weather, the deposition of organic and inorganic matter and the microbial growth. The optical and radiative properties of building materials are also affected by this aspect (Paolini et al. 2016; Sleiman et al. 2015). Cool materials with initial surface reflectance greater than 0.8, weathering and soiling can reduce this value by 0.20-0.30 (Paolini et al. 2016)
The scope of this study is the development of two new cool material that will be installed on Cadiz and London, under the framework of Horizon2020 project ReCO2ST[1], taking into consideration each site's climate and each demo building's characteristics. The simulations were made by using Open Studio 2.7 and Energy Plus 8.9.

PREVIOUS WORK

Brunel University has already made some studies on cool roofs. More specific, a first study took part in a natural ventilated office building in London, UK, in 2013(Kolokotroni, Gowreesunker, and Giridharan 2013). The scope of this study was to investigate the impact of a reflective paint on the flat roof of the building. During the summer period, before and after the application of cool roof, all the environmental parameters were monitored. Finally, the simulation, made by TRNSYS, showed that a reduction of internal temperature has been achieved after the application of cool materials. Moreover, the demand for cooling was reduced, improving the thermal comfort conditions by 2.5 ^{o}C. In contrast, the demand for heating was increased by 10%. The second study of Brunel University focused on the application of cool painting on the roof of low-income houses in Jamaica, in Brazil and in Ghana, in 2018 (Kolokotroni et al. 2018). Annual simulations made by Energy Plus, indicated a significant reduction of surface temperatures by 3.2-5.5^{o}C and internal air temperatures by 0.75-1.2^{o}C. In the three locations, similar cooling demand was noticed, thus the aging of the cool material reduced the annual energy saving by 22- 26 kWh/m^2. In a recent study (Shittu et al. 2020) the energy and environmental impact of cool paint was calculated for case-study house in Jamaica and Sicily. It was found that significant net energy benefits are possible in both locations by a cool roof, more pronounced in Jamaica, which has no heating demand; savings are comparable with thermal insulation reductions. The environmental impact of cool paint is lower than a variety of thermal insulation materials with the exception of water depletion potential. The main hotspots of the cool paint are the production of the polymer followed by the production of the pigment.

[1] https://reco2st.eu/

Moreover, Technical University of Crete in collaboration with Technological Educational Institute of Crete (Kolokotsa et al.2012), analyzed the application of cool roof technology in a laboratory building in Iraklion, Crete. The building was monitored before and after the implementation of cool roof technology. The results of the study showed a reduction of energy consumption in air-conditioned buildings and a significant improvement in thermal conditions in non-air-conditioned buildings.

METHODOLOGY

Performance of cool materials developed

Two new cool materials were used for the simulations. Specific climate conditions for the summer and buildings' characteristics of each case study are taken into consideration for the development of cool materials. Currently, the cool materials are under test in laboratories and the actual implementation will take place in Cadiz, Spain and in London, UK.

For the building in Cadiz, a two-component acryl-epoxy hybrid water base coating for bitumen waterproofing, concrete, sheet metal, round tiles and shingles was developed. The product consists of 2 different liquids that are mixed on site. The mix is then painted on the desired surfaces. The properties of the coating are: SR: 0.89, IE: 0.89 and SRI: 114. For London, a PVC roofing membrane with TiO_2 developed, while its properties are: SR:0.87, IE:0.90 and SRI:110. Moreover, for both case studies, values of SR: 0.80, IE: 0.89 and SRI: 98 are predicted after two years usage without any cleaning or maintenance.

Figure 1 Example of roof application of the developed material that will be applied in Cadiz, Source: INDEX Construction Systems and Products Spa

Case study 1 in Cadiz

The first case study is a building situated in Cadiz, Spain. More specific, it consists of 5 floors (with the ground floor), having 28 habitable apartments. Each floor height is 2.80m. The total building area is 1.873 m^2, while the habitable area is 1.557 m^2.

Figure 2a South facade **Figure 2b** North facade

The building has no cooling and heating system, while the windows are single glazed and the doors are metal frames. The façade wall consists of artificial stone, expanded polystyrene and gypsum plaster. The ground floor has marble, expanded polystyrene and concrete. Finally, the roof has sand, expanded polystyrene, concrete and marble. Figure 3 depicts the simulation of the building in Cadiz using OpenStudio/Energy Plus.

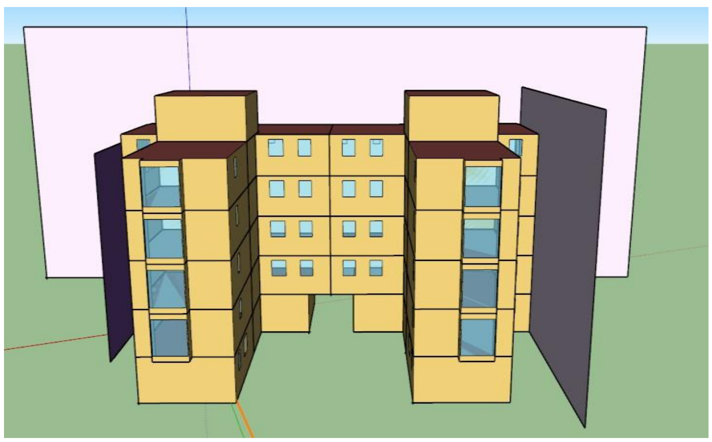

Figure 3 Modeled building in Cadiz in OpenStudio

Table 1 denotes the internal gains that used for the simulation, which consist of the people, the lights and the electrical equipment. Table 2 depicts the cooling and heating setpoint for Cadiz.

Table 1. Simulation parameters for internal loads in Cadiz

Internal Loads-simulation parameters	Values
People	33.3 m^2/person, 0.8 Fraction Radiant
Lights	4.4 W/m^2, 0.9 Fraction Radiant
Electrical Equipment	8.8 W/m^2, 0.1 Fraction Latent

Table 2. Simulation parameters for setpoint in Cadiz

Summer period 1/5-31/10	Cooling setpoint (^{o}C)
00:00-08.00	27 ^{o}C

08.00-12.00	50 ^oC
12.00-24.00	25 ^oC
Winter period 1/1-30/4 & 1/11-31/12	**Heating setpoint (^oC)**
00:00-06.00	17 ^oC
06.00-22.00	20 ^oC
22.00-24.00	17 ^oC

Case study 2 in Brunel, UK

The second case study is a building situated in Uxbridge, West London. It consists of one of three similar apartments (23 total apartments) with total building area 4700m^2, built in 1979 (Figure 4a). The whole building belongs to the estate of Brunel University London and is used for student accommodation.

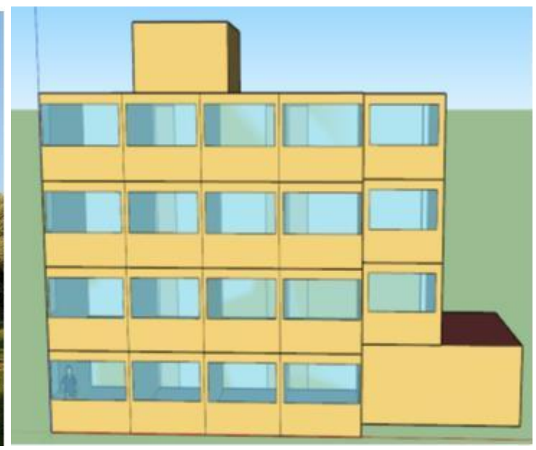

Figure 4a Brunel case study **Figure 4b** Modeled building in London in OpenStudio

The construction of this building is typical of 1970's. More specific, it consists of bricks for the walls with no insulation and a flat roof of timber construction with limited insulation. Apart from that, double glazed windows with openable parts were installed in 2005. The heating system in the apartments is through gas fired boilers for heating and hot water production. The building is serviced by a heating system and no cooling system exists. There is no mechanical ventilation throughout the building and the ventilation in each apartment is manual and it depends on the occupant. Figure 4b depicts the simulation of the building in London using OpenStudio. Table 3 denotes the internal gains that used for the simulation, which consist of the people, the lights and the electrical equipment. Table 4 depicts the cooling and heating setpoint for Brunel.

Table 3. Simulation parameters for internal loads in Brunel

Internal Loads-simulation parameters	Values
People	1 person/room, 0.3 Fraction Radiant
Lights	16 W/room
Equipment Laptop (in bedroom)	65W/room

Table 4. Simulation parameters for setpoint in Brunel

Constant Heating setpoint for kitchen &bedrooms	25 °C
Constant Cooling setpoint for kitchen &bedrooms	100 °C

RESULTS

Cadiz results

The results of simulation for the first case study in Cadiz are shown in Figure 5 and Figure 6, respectively. More specifically, cool materials are applied on the roof, where there is no HVAC system. Figure 5, presents the room air temperature before and after the application of cool materials, in a hot day during the summer. The weather file that used is EPW file by Meteonorm[2]. A significant reduction in air temperature is observed, especially during the midday, where the difference reached 5 °C. As a result, this reduction leads to better thermal comfort for the occupants. Moreover, Figure 6 depicts the reduction of surface temperature that the construction achieves due to the application of cool material.

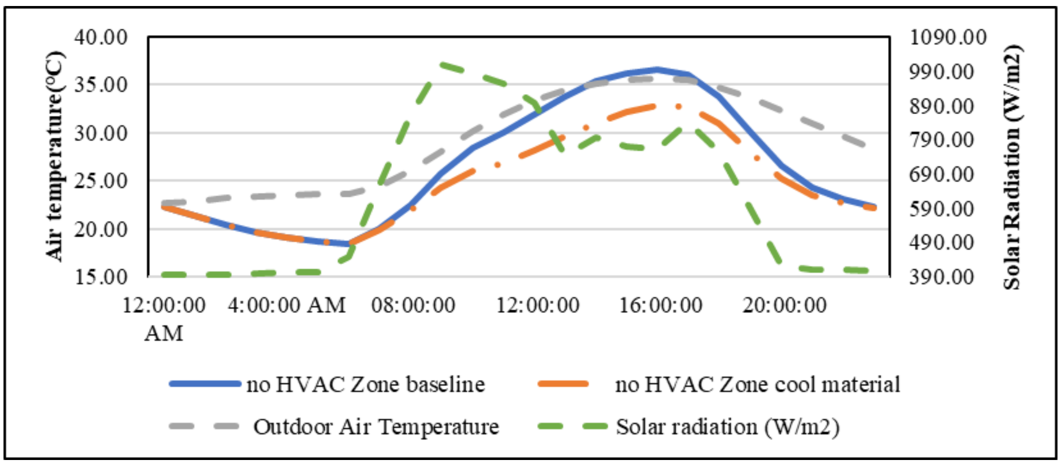

Figure 5 Room air temperature at the top floor of Cadiz demo site before and after application of cool materials

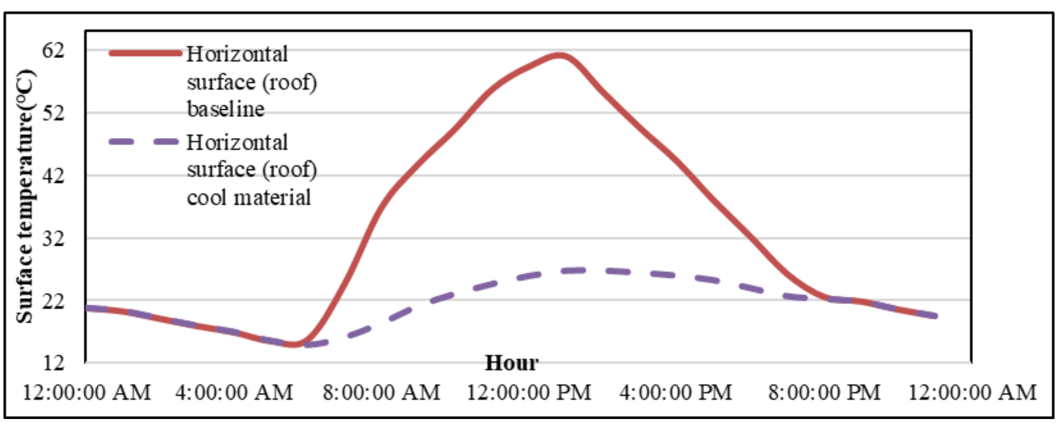

Figure 6 Surface temperature at the top floor of Cadiz demo site before and after application of cool materials

[2] https://meteonorm.com

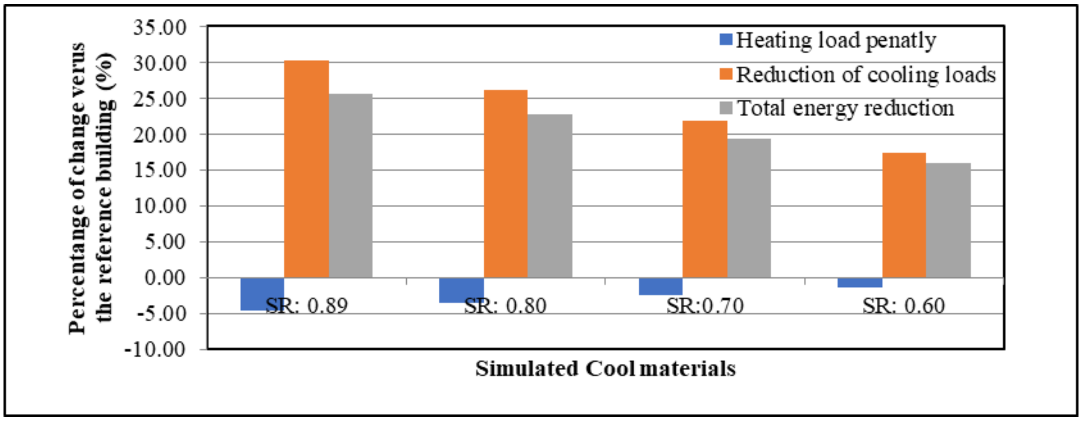

Figure 7 Thermal energy reduction from the application of cool roofs into demo building of Cadiz

Figure 7 depicts the thermal energy performance from the application of cool materials in the roofs. A significant decrease in the cooling needs is observed, thus the heating needs are increased almost by 5%. Moreover, there is an overall decrease in the total energy demand for all aging cases (SR: 0.80, 0.70, and 0.60).

London results

The results of simulation for the second case study in London are shown in Figure 8 and Figure 9, respectively. More specific, cool materials are applied on the roof. Figure 10, shows the daily fluctuation of the room air temperature before and after the application of cool materials, during a summer day. The weather file that used is EPW file by Meteonorm[2]. The surface temperature results are depicted in Figure 11, presenting a considerable decrease of surface temperature. Finally, taking into account that there is no cooling system in the building. Apart from the increase in heating demand in the proposed material (SR: 0.87), Figure 10 depicts the overall increase of heating needs for all aging cases (SR: 0.80, 0.70, 0.60).

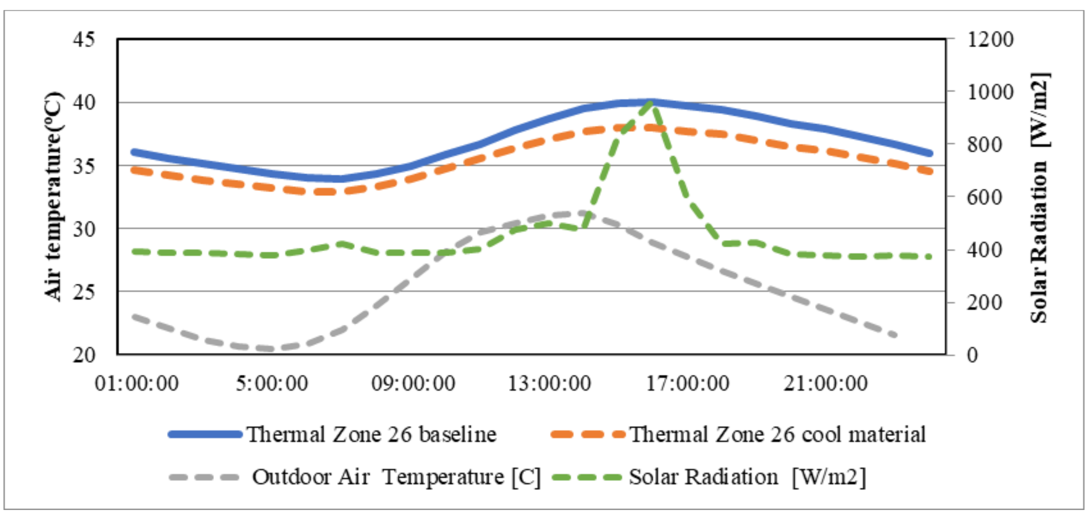

Figure 8 Room air temperature in London demo site

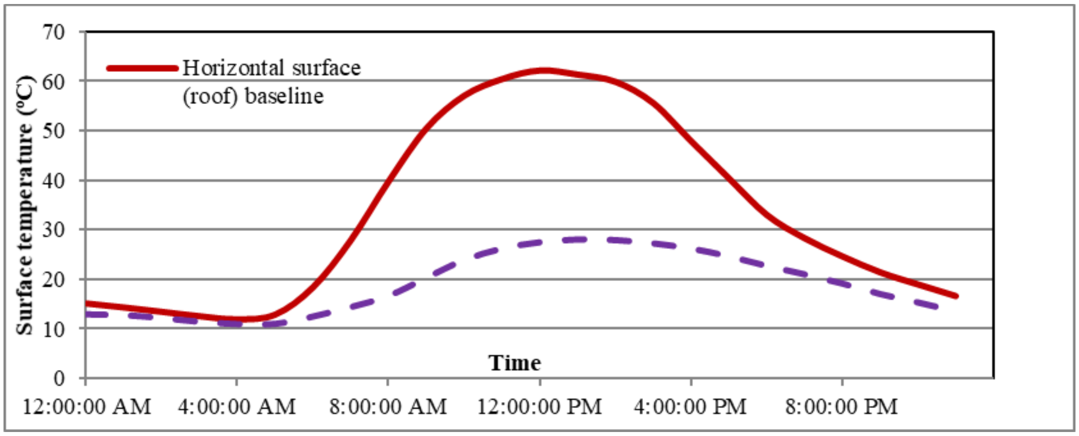

Figure 9 Surface temperature of a horizontal surface at London demo site

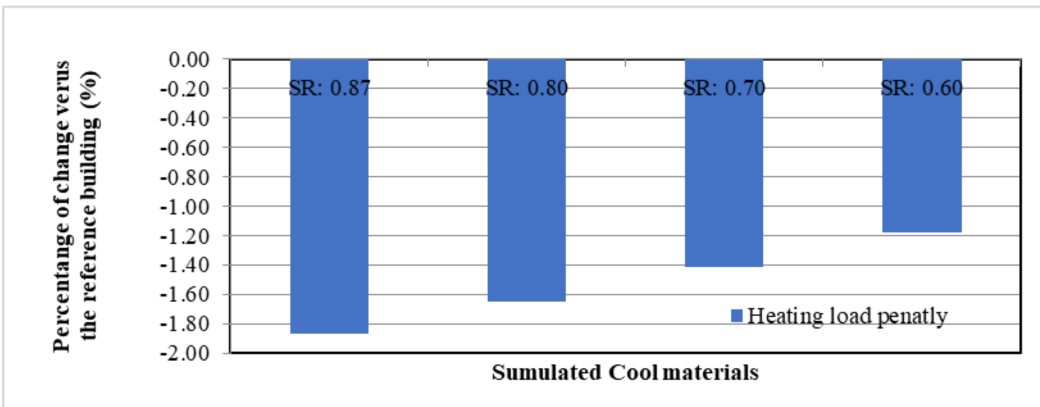

Figure 10 Heating energy penalty from the application of cool roofs into demo building of London

CONCLUSION

The present study aims to analyze residential buildings' thermal behavior before and after the application of cool materials. The performance of cool materials is evaluated using OpenStudio/Energy plus to simulate the current situation and the scenario with the proposed cool material that will be applied on the roof of each case study.

The application of cool materials in buildings with high solar radiation intensity during the summer, can lead to:

- Significant decrease of cooling needs in a building with no HVAC system
- Better thermal comfort for the occupants of the building during the summer

The reduction of cooling demand and the comfort are closely related to external climatic conditions, building characteristics, construction and the use of spaces concerning the internal heat gains.

After the simulations, the technical work will continue in the laboratories and the actual implementation will take place in Cadiz and in London, respectively.

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NOMENCLATURE

SR= solar reflectance

UHI=Urban Heat Island

IE=infrared emittance

SRI= solar reflectance index

ASTM= American Society for Testing and Materials

PVC= Polyvinyl Chloride

CRRC=Cool Roof Rating Council

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