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Retroreflective façades for urban heat island mitigation: Experimental investigation and energy evaluations

Federico Rossi [a,1], Beatrice Castellani [b,*], Andrea Presciutti [a,2], Elena Morini [a,2], Mirko Filipponi [a,2], Andrea Nicolini [a,3], Matheos Santamouris [c]

[a] CIRIAF, University of Perugia, via G. Duranti, 67, 06125 Perugia, Italy
[b] Consorzio IPASS Scarl, via G. Guerra, 23, 06127 Perugia, Italy
[c] Physics Department, University of Athens, Panepistimioupolis, 15784 Athens, Greece

HIGHLIGHTS

- Retro-reflective (RR) materials are an effective strategy for mitigating UHI.
- Optical properties of RR materials are assessed by a new experimental facility.
- Angular distribution of reflected radiation is assessed during daytime.
- RR component is treated as a diffusely reflected radiation by a reduction factor.
- An algorithm evaluates the cooling potential of RR materials in urban canyons.

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ABSTRACT

The optimization of optical properties of buildings' envelope and urban paving represents an important research field for reducing the urban heat island effect. The overheating of a surface exposed to sunlight can be reduced by improving solar reflectance. In this sense, several studies have demonstrated the positive effect of cool materials on UHI mitigation.

In addition to traditional cool materials, retroreflective (RR) materials have been recently proposed for this application. The present paper aims at the assessment of angular reflectance of RR films for several inclination angles of solar radiation. To reproduce variation of solar radiation's inclination during the daytime, an *ad hoc* experimental setup was designed and used. Characterization of RR materials when hit by solar radiation with different inclinations allows to assess their behaviour on daytime if used as novel urban coatings for mitigation of the UHI phenomenon.

Measurement results are used as input for an original algorithm which allows to quantify cooling potential of RR materials in terms of energy reflected and sent beyond the urban canyon. The experimental characterization and energy evaluations showed that RR materials could be effectively applied as coatings on urban paving and building envelope, in order to reduce the circulating energy into the canyon.

1. Introduction

The Urban Heat Island (UHI) effect is defined as the rise in temperature of any man-made area, resulting in a well-defined, distinct "warm island" represented by the urban area among the surrounding natural landscape [1]. The complex phenomenon of UHI derives from several aspects.

Firstly, due to interreflections between urban surfaces, shortwave radiation is more efficiently absorbed than in rural areas. Furthermore, urban surface roughness decreases the mean wind velocity and reduces the convective heat removal. An additional contribute is also given by the heat gain due to anthropogenic sources and the lower evaporation due to the reduction of vegetated areas [2–6]. UHI has been measured in different cities around the world [7,8] and affects negatively buildings' cooling energy demand thus resulting in peak electricity demand [9].

* Corresponding author. Tel.: +39 075 505 1704.
E-mail addresses: federico.rossi@unipg.it (F. Rossi), castellani@ipassnet.it (B. Castellani), andrea.presciutti@unipg.it (A. Presciutti), morini@crbnet.it (E. Morini), filipponi.unipg@ciriaf.it (M. Filipponi), nicolini.unipg@ciriaf.it (A. Nicolini), msantam@phys.uoa.gr (M. Santamouris).
[1] Tel.: +39 075 505 1704.
[2] Tel.: +39 0744 492969.
[3] Tel.: +39 075 5853714.

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Nomenclature

A	apparent extraterrestrial irradiance (W/m^2)
B	overall broadband value of the atmospheric attenuation coefficient for the basic atmosphere (dimensionless)
α	angle between the perpendicular direction to the surface and the direction of reflection (deg, values between −90° and 90°)
β	elevation angle (°)
γ	angle under which the reflected energy remains inside the canyon (°)
D	width of the urban canyon (m)
$E_{In\%}$	energy reflected by the façade that remains inside the canyon (%)
$E_{Out\%}$	energy reflected by the façade outside the canyon (%)
g	day of the year (from 1 to 364)
H	height of the canyon (m)
H_s	height of façade's area hit by solar radiation (m)
θ_i	angle of incidence (°)
θ_{lim}	RR limit angle (°)
$In\%_{,n}$	energy reflected by the n-th area that remains inside the canyon (%)
L	longitude of the site (°)
λ	latitude of the site (°)
n	concentration factor
χs	surface tilt (°)
Ψs	surface azimuth (°)
Ψ	solar azimuth angle (°)
$W_{d,i}$	incident direct solar radiation
$W_{r,a}$	reflected energy in the a direction (W/m^2sterad)
$W_{r,\perp}$	reflected energy in the perpendicular direction (W/m^2-sterad)

Bueno et al. [10] show that the energy consumption of residential buildings can be modified by 20% for a typical 4 K daily-maximum UHI effect. At the same time, the energy performance of buildings can have an impact on outdoor air temperatures, mainly through the waste heat emissions from outdoor air-conditioning equipment [10]. In order to tackle these reciprocal interactions between buildings and the urban climate, several innovative and effective mitigation strategies have been proposed: energy saving solutions [11], efficient energy production systems [12–17], innovative materials and solutions for paving and cladding[18–20], land cover change [21], urban climate prediction tools [22,23].

In the frontiers of energy saving studies, cool materials, such as cool roofs [24,25,6,26], cool pavements [27,28] and other innovative solutions such thermochromic coatings [3], are addressed to have substantial potentials to mitigate UHI effects and improve thermal performance of the building.

Several contributions about the demonstrated positive effect of cool materials on UHI mitigation are also available in literature [29–33].

In addition to traditional cool materials, retroreflective (RR) materials have been recently proposed as an effective innovative solution for improving urban climate conditions during summer and, moreover, for reducing building energy requirement for cooling [34].

Retroreflectivity refers to the ability of a specially engineered surface to preferentially reflect incident light back towards its source regardless of the direction of incidence. A large number of RR films are available, aimed primarily at the road, rail and air transport industries for signs and route markers that are highly visible in all weather conditions [35].

The optic behaviour - in terms of angular distribution of reflected radiation – of some RR commercial samples have been already assessed for perpendicular incident radiation [34]. According to this study, RR materials may be treated as well as common diffusive surfaces by the introduction of a proper reduction factor and they were proposed for reducing mutual radiative effect among buildings located in close proximity [34].

Another model was proposed to calculate the hourly reflectance of directional reflective materials as a function of zenith and azimuth angles [36]. It is based on seasonal reflectance and assigns as the winter reflectance the average reflectance of these materials and as the summer reflectance the reflectance according to a 20° zenith towards the reflective side.

The present paper aims at the assessment of angular reflectance of RR films for several inclination angles of solar radiation. To reproduce variation of solar radiation's inclination during the daytime, an *ad hoc* experimental setup was designed and used. Characterization of RR materials when hit by solar radiation with different inclinations allows to understand their behaviour during the day if used as novel urban coatings for mitigation of the UHI phenomenon.

The application of RR materials as new urban coatings is a novel and unexplored research field and presents considerable potential in: (i) reducing the heat content in the UHI boundary, (ii) reflecting the solar radiation beyond the urban canopy, (iii) reducing possible inter-building effects in terms of mutual reflection between facing buildings located in close proximity.

Investigation in this sense gathers importance also because the application of traditional cool materials with diffusive reflectance seems not to solve issues related to the growing urban density, such as an increase in buildings' proximity and canyoning phenomena.

In order to quantify benefits obtainable from RR materials in canyons, an algorithm was used. RR materials' behaviour is compared to that of traditional diffusive materials in terms of amount of solar radiation reflected beyond the urban canyon.

2. Experimental section

2.1. Retro reflective samples

For the purpose of this work, five RR samples are chosen following the [37] which provides the basic information regarding RR sheeting types and adhesive backing classes.

Samples are commercial retroreflective flexible adhesive sheetings whose typical applications are permanent-type traffic control and guidance signs and delineators. Even if adhesive plastic sheetings are not the optimal solution for building envelopes, the characterization of such materials is undoubtedly useful for the development of proper retroreflective building coatings.

In this experimental campaign, all films were tested in a clean, dry condition. The next step of the research will consist in the performance evaluation of RR materials during weathering and dusting process.

The selected samples (Fig. 1) have the following characteristics:

– Sample 1: ASTM Type II (medium–high-intensity retroreflective sheeting). It is a glass-beaded, self-adhesive film with excellent resistance of corrosion and solvent. It is supplied by Daoming Optics&Chemical.
– Sample 2: ASTM Type I (medium-intensity retroreflective sheeting).It is a PET (Polyethylene terephthalate) hazard warning tape. It is supplied by Daoming Optics&Chemical.