Optic-energy performance improvement of exterior paints for buildings

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A B S T R A C T

Several strategies to mitigate urban heat island (UHI) phenomenon have been proposed or developed, such as highly reflective envelopes of buildings and urban paving. The reduction of the temperature of a surface exposed to sunlight can be obtained by improving urban materials’ solar reflectance. Directional reflective materials, and in particular retro-reflective (RR) materials have been proposed in addition to traditional diffusive cool materials. Previous studies investigated the performance of commercially available RR sheets that were typically used for street signs. The present study is aimed at investigating the performance of RR materials for building application. An exterior paint typically used in Italian cities has been provided with glass beads with different sizes. The angular reflectance of one diffusive and two retro-reflective samples is examined at three different wavelengths. The diffusive behavior is kept by the diffusive sample for the three wavelengths. The retro-reflective behavior is kept by the RR samples for low angles of incidence, for the three wavelengths. For high angles of incidence (greater than 60°) the retro-reflectivity is lost by the RR samples. The experimental characterization showed that RR materials could be effectively applied as coatings on building envelope, in order to reduce the energy trapped within the urban canopy and thus to reduce the UHI effect. Further investigations are foreseen to propose a process to produce industrial retro-reflective materials for building application.

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1. Introduction

Summer days in man-made areas can reach temperatures of several degrees greater than rural areas. This is due to the phenomenon that in meteorology and climatology is called Urban Heat Island (UHI) that causes a warmer microclimate within the urban areas, compared to the surrounding rural and remote areas.

The phenomenon has been widely investigated by researchers that have assessed that its intensity is due to the local meteorological conditions, the lack of vegetation, the absorption of solar radiation of dense constructions’ surfaces, the growing anthropogenic heat fluxes related to buildings cooling and heating, and the urban patterns where the presence of buildings causes the so-called canyon effect where winds are obstructed by buildings and thus are not able to flux nor to cool the air [1–6].

UHI has negative effects on the urban built environment: it increases energy requirements for summer cooling, exacerbates discomfort, heat risks and mortality, pollutants concentration and the carbon footprint of the urban areas [7–12].

Solar reflectance of coating materials for building envelope and urban pavement represents an important optic-energy property to be investigated as a countermeasure to the urban heat island effect [13–18]. Numerical simulations and experimental investigations carried out worldwide demonstrated that highly reflective materials, integrated also with other thermal energy storage technologies and energy saving solutions [19–23], constitute an acknowledged countermeasure the UHI effect [24–29]. 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 [30]. With a diffusive behavior, in fact, part of the reflection will be absorbed by neighboring buildings. In addition, the reflected radiation, coming from diffusive vertical surfaces hits pavements and roads, thus resulting in an increase of the absorbed radiation and, therefore, in a limitation of their positive effect on UHI.
An innovative family of "cool materials" is formed by retro-reflective (RR) materials. RR materials have the property to reflect light backward to the incident direction. Currently, RR materials are employed for various safety purposes, as road signs, work clothes and the traffic safety applications, and they are not commercially available for use as building coatings. They are being investigated for building applications by several research groups in the world. Urban patterns coated with RR materials have the potential to reduce the UHI, since the reflected sunlight reaching neighboring buildings and roads is reduced [31,32].

Studies on RR materials found in literature focused on the analytical modelling of RR materials' behavior [33], the evaluation of the optic properties of RR samples for several angles of incidence with respect to perpendicular direction [32], the evaluation of RR cooling effect at urban canyon level in terms of reduction of the energy circulating inside the canyon [34–36], theoretical geometrical-optic analysis of RR glass beads applied to building coatings [37], the improvement of durability of commercial RR materials via glass application for buildings [38].

In particular, it was pointed out that RR materials reflect radiation mainly backward to the incoming direction only for low incidence angles, while they lose this property for high incidence angles. The angular distribution of the reflected radiation depends on cos^n, where the exponent “n” depends on the material and describes the concentration of the reflected radiation around the direction of the incident radiation [32].

The present work is connected to the international research activities on RR materials and aims at giving a contribution on the development of RR coatings suitable for building applications.

2. Motivation

The intention of this work is to provide experimental results useful for the development of a RR material, in form of paint, conceived for covering urban façades and pavements. The results available in literature always refer to commercial existing RR materials, born to address other types of applications.

As concerns the existing RR materials, their structure is roughly classified into two types, one with glass beads and the other with prisms. Many retroreflective highway signs and lane markings use thousands of tiny glass beads that are bonded to the roadway with a strong binder. Instead of simply scattering light, as normal paint pigments do, glass beads turn the light around and send it back in the same direction, as shown in Fig. 1.

In order to make RR materials based on this principle, useful as building coatings to fight the UHI effect, their retro-reflective performance should be better investigated.

In this research, a traditional paint typically used for exterior buildings' surfaces is provided with glass beads to obtain a new RR colored paint suitable for buildings. The developed samples are characterized in terms of angular distribution of the reflected radiation for three different incident wavelengths. As yet, the characterization of RR behavior of building materials has been carried out using light sources with an emission spectrum very similar to the solar one. This investigation, instead, will give new data on the spectral behavior of the RR material to understand whether the retro-reflectivity is kept over the VIS range. A further investigation, here proposed, is related to the influence of the glass beads' size on the sample's RR property and on the enhancement of the optic performance of the building paint.

3. Materials and methods

3.1. Materials

For the purpose of this work, three samples were developed laying down conventional building painting over a transparent sheet. The first sample is constituted by a light colored diffusive paint, which is typically used for exterior buildings in Italian cities. Light colors are in fact usually chosen for exterior walls, since they can be well contextualized to the built environment and respect landscape and historical-architectural constraints. The two other samples were developed applying glass spheres of different sizes on the paint when it was still wet in order to provide retro-reflective properties to the paint.

The second investigated sample has small glass spheres with a diameter in the order of 0.1–0.2 mm, while the third sample is

<table>
<thead>
<tr>
<th>Color</th>
<th>Wavelength (nm)</th>
</tr>
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<tbody>
<tr>
<td>Blue</td>
<td>Between 406 and 482 nm</td>
</tr>
<tr>
<td>Green</td>
<td>532 nm</td>
</tr>
<tr>
<td>Red</td>
<td>Between 620 and 780 nm</td>
</tr>
</tbody>
</table>

Fig. 2. Investigated Samples.

Fig. 3. Enlarged images of the investigated Samples: a) SS, b) BS.

Fig. 1. Glass beads for retro-reflective property.
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