Energy & Buildings 179 (2018) 121–132

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

Effects of aging on retro-reflective materials for building applications

Elena Morini [a,*], Beatrice Castellani [a,b], Andrea Nicolini [a,b], Federico Rossi [a,b], Umberto Berardi [c]

[a] CIRIAF, University of Perugia, Via G. Duranti 63, 06125 Perugia, Italy
[b] Engineering Department, University of Perugia, Via G. Duranti 67, 06125 Perugia, Italy
[c] Department of Architectural Science, Ryerson University, 350 Victoria street, Toronto, ON M5B2K3, Canada

ARTICLE INFO

Article history:
Received 16 April 2018
Revised 5 September 2018
Accepted 8 September 2018
Available online 19 September 2018

Keywords:
Cool materials
Retro-reflective materials
Aging tests
Solar energy
Urban heat island

ABSTRACT

Cool materials have been proposed for building applications given their potentialities in reducing building energy consumption, urban heat island effects, and global warming. Among cool materials, retro-reflective (RR) ones have been recently proposed for their ability to reflect backwards the incidental striking solar energy. This property is useful in densely urbanized areas, in urban canyons patterns, and in urban areas with buildings of different heights, because it avoids that the reflected energy contributes to the overheating of the neighbor buildings and structures. This study aims to predict the long-term performance of some RR tiles and paints intended for building applications. To this purpose, laboratory accelerated aging tests as described in the ASTM G154 were performed to determine the long-term material properties within a much shorter time than with outdoor weather aging. The samples show minimal changes in the reflectivity, directional reflection, and colorimetry. Finally, this paper shows that the RR character of the investigated materials and their urban cooling potential would be preserved.

1. Introduction

Urban population is growing significantly and consequently, the need of more sustainable urban areas has become a key issue worldwide. For several decades, research has been focused on techniques and technologies for energy efficiency with the aim of minimizing the effects caused by the anthropogenic modification of natural landscapes. In fact, artificial surfaces increase the so called “Urban Heat Island” (UHI) phenomenon and the energy demand, as a consequence of the fact that urban temperatures are higher than in the rural areas. UHI increases significantly the cooling energy demand while slightly decreases the heating energy demand [1,2]. The increased urban temperatures lead to higher energy consumption not only for cooling but also for services and systems, boosting the human carbon footprint and the environmental implications [3,4]. In general, there is a growing awareness that strategies related to urban design have to take into account both socioeconomic perspectives and environmental sustainability [5]. Within this aim, cool materials gained wide attention in the research and technological fields as effective technologies for energy efficiency and sustainable urban design [6–10]. The several benefits of cool materials on urban microclimate have been widely investigated: the reduction of energy consumption for summer cooling [7], the mitigation of UHI [8], and the mitigation of global warming thanks to the reduced energy trapped within the atmosphere [9].

The latest innovative researches about cool materials proposed the use of retro-reflective (RR) materials [10–13]. Their property of reflecting backwards the striking energy makes them effective cooling strategy, in different urban patterns (e.g. blocks and canyons), latitudes, and expositions [11–13]. Commercial RR films, optimized tiles and paints, and innovative RR films for transparent windows have been investigated in several recent researches [11–14]. The results showed that RR vertical walls in an urban canyon can increase the radiation energy reflected outwards an urban canyon up to 5% [15]; for RR windows, downward reflected solar irradiance reaching the street level was reduced from the 50 to 80% range for the low-E glass, to less than 40% for the RR film [14]. However, the beneficial effects of cool materials can be compromised by ageing processes due to physical degradation and soiling that modify their reflectivity and emissivity. Light (especially UV radiation), heat, moisture, and soiling are the main causes for the weathering and degradation of a material. Short wavelengths have high proton energies and are easier absorbed, causing sometimes the breaking of the chemical bonds. Temperatures stresses cause mechanical ones for thermal expansion. Similarly, wet and dry cycles cause volume expansions and reductions that lead to mechanical stress and crack fatigue too [16]. Soiling instead is due to the deposition of atmospheric aerosols and dust, biomass

* Corresponding author.
E-mail addresses: morini@crbnet.com, morini@crbnet.it (E. Morini).

https://doi.org/10.1016/j.enbuild.2018.09.013
0378-7788/

Table 1.
List of the samples investigated in this paper.

	Paint (P) or Tile (T)	Color	Spheres
1	P	Light paint	Glass
2	P	Light paint	Barium glass
3	P	Light paint	Aluminum-barium
4	P	Light paint	Aluminum-barium fluorochemically treated
1	T	Grey tile	Barium glass
2	T	Grey tile	Aluminum-barium
3	T	Grey tile	Aluminum-barium fluorochemically treated
4	T	Brown tile	Barium glass
5	T	Brown tile	Aluminum-barium
6	T	Brown tile	Aluminum-barium fluorochemically treated
7	T	Light brown tile	Glass
8	T	Light brown tile	Barium glass

accumulation and microbiological growth [17,18]. Atmospheric gases and pollutants can cause oxidation and corrosion, biological growth might be caused by moisture retained in porous structures and the deposition of atmospheric particulate matter can worsen a material performance [19,20].

In order to assess the long-term performance of cool materials, natural and artificial aging procedures have been approached and regulated in standards. Natural procedures foresee the exposure of the samples for long periods (often of several years), and the contemporary use of a weather conditions [21]. Artificial aging tests, instead, allow to accelerate the degradation and to investigate the material behaviors under controlled environmental conditions and in shorter times [16].

Several papers investigated the effect of ageing on the performance of cool materials. For a flat cool roof with initial solar reflectance higher than 0.80, natural ageing caused a solar reflectance decrease by up to 0.16, after three years of exposure in moderately polluted urban areas [20]. After four years, a decrease of almost 25% of the cool roofs' albedo was found in Athens (Greece) [22]. The surface temperature difference between the aged and the new cool roof reached 7–12 K. However, the reflectivity loss could be almost totally regained (70–100%) through washing with water, detergents or algaecide [23].

The effects of thermal stresses and UV exposure are less easy to recover and hence deserve more attention. In particular, the present paper aims to investigate the effect of artificial ageing on the characteristics of RR materials. The properties of the new samples were evaluated in [15,24]. To date the performance of RR aged materials has not yet been assessed. As mentioned in [16], the weathering characterization should be studied as a part of the materials production, measurement, test design, exposure and evaluation as a whole. In this paper, twelve RR samples are submitted to ageing cycles that simulate light, heat, and moisture detrimental effects. The effects of particulate and biological growth are beyond the objective of this investigation. The materials are characterized by measuring their reflectivity, their retro-reflectivity and their color variation before and after the aging cycles. The results related to the directivity are then used in an algorithm that allows to estimate the amount of energy reflected outside an urban canyon. A comparison with the performance of the new samples is also provided, in order to assess their potential deterioration.

2. Materials and methods

2.1. Materials

The investigated samples are listed in Table 1 and depicted in Fig. 1. The 1P to 4P ("P" stands for "paint") are made on a base of a light paint. 1T to 8T ("T" stands for "tiles") are made on a base of tiles of different colors, covered with a transparent paint for exterior application which is UV resistant. The samples are made of different kind of spheres spread on the wet paints: small glass spheres (diameter in the order of 0.1–0.2 mm), barium glass spheres (diameter in the order of 0.044–0.053 mm), aluminum-barium spheres (hemispherically aluminum coated barium titanate glass microspheres, with average diameter 0.04–0.06 mm), aluminum-barium fluorochemically treated spheres (hemispherically aluminum coated barium titanate glass microspheres with a fluoropolymer coating, with average diameter 0.04–0.06 mm).

2.2. Methodology

The samples were characterized by spectrophotometric analysis, directional characterization, and colorimetric analysis. After having measured the samples in pristine conditions, aging processes were realized in order to predict the long-term performance of the samples.

Laboratory accelerated aging tests allow to determine the long-term material properties within a much shorter time than with outdoor (weather) aging. The selection of the most correct exposure and measurement intervals was an important aspect of this study. In fact, the exposure levels were chosen high enough to accelerate the aging process within the allowable testing time, but they were chosen carefully to avoid introducing failure modes which would never occur under normal use conditions. The most critical climate strains that act as aging factors for building materials are: solar radiation, i.e. ultraviolet (UV), visible (VIS), and near-infrared (NIR) radiation; ambient infrared (IR) heat radiation; temperature cycles and extreme temperatures; water, e.g. moisture, relative air humidity, rain (precipitation), and wind-driven rain; physical strains, e.g. snow loads; wind; pollutions, e.g. gases, dirt, and dust; microorganisms, e.g. mold and bird droppings. The relative importance of each one of the previous factors depends on the climate conditions of use as well as on the actual building material and its resistance to climate exposure conditions. Generally, it is not possible to simulate all the possible weathering conditions in a laboratory setup, and often, this might not be even necessary. In fact, laboratory tests considering only temperature, light, and moisture-related effects are often adopted for assessing the long-term performance of building materials [25]. Focusing just on these three weather parameters is generally sufficient unless the material to test is planned to be used in an environment with some specific weathering characteristics.

Elevated temperatures increase the kinetic reaction rates within the molecules of the materials and accelerate the chemical degradation processes. Consequently, the time needed for performing long-term weather aging may be shortened by increasing temperature at which a material is exposed. However, exposing materials to extremely high temperature, which would never be experienced