Energy and Buildings 69 (2014) 417–425

Contents lists available at ScienceDirect

Energy and Buildings

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

On the cooling potential of cool roofs in cold climates: Use of cool fluorocarbon coatings to enhance the optical properties and the energy performance of industrial buildings

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ARTICLE INFO

Article history:
Received 11 October 2013
Accepted 19 October 2013

Keywords:
Cool materials
Fluorocarbon coating
Industrial building
Temperate climatic conditions
Energy efficiency
Reduction of cooling load

ABSTRACT

Rejection of solar gains is the aim of passive cooling strategies in any type of building and any climatic region. The extent of cool materials' applicability depends on the external climatic conditions and internal heat gains. The aim of the present paper is to analyse the contribution of an innovative cool fluorocarbon coating in the reduction of energy demand for cooling when applied in an industrial building with increased heat gains under temperate climatic conditions. The material is tested using accelerated weathering procedures and its optical properties, i.e. solar reflectance and infrared emmitance are measured. There is an increase of 120% of the roof's albedo by the application of cool material. Regarding the heating and cooling loads there was a decrease of 73% for cooling while there was a minor heating penalty of 5%.

1. Introduction and state of the art

Extensive urbanisation has created economic, social, energy and environmental challenges for the built environment [1]. The deterioration of the urban environment and the urban heat island has become a common problem in many major cities worldwide while the temperature increase intensifies the energy demand for cooling [2–5]. Implementation of urban microclimate improvement and energy efficiency strategies such as the application of cool materials has become an important priority in order to reduce the energy demand for air conditioning in buildings and contribute to cities' sustainability [6,7].

Rejection of solar gains is the aim of passive cooling strategies in any type of building under warm climatic conditions. The extent of cool materials applicability is dependent on the severity of external conditions and internal heat gains [8]. Cool roofs work by reflecting solar radiation and therefore rejecting solar heat gains at the opaque external surfaces of the building [9,10]. Heat transfer to the internal space is therefore reduced while the magnitude of the reduction is determined mainly by the solar radiation intensity, the temperature difference between inside and outside as well as the roof's constructional characteristics.

Under hot climatic conditions, rejection of buildings' heat gains is essential to maintain comfortable conditions without increasing considerably the use of air conditioning. The effect of cool materials in hot climatic conditions are studied by various researchers [11–16]. In most cases a reduction of the cooling load varying from 20% to 40% is revealed by the application of cool roofs while a considerable indoor comfort improvement is noticed [17].

Although cool materials are considered a reliable solution for hot climatic conditions, they can be a feasible solution in temperate climatic conditions also, i.e. for low solar radiation, moderate air temperatures in the summer and cold temperatures during the winter. In buildings of such climates, rejection of heat gains should be considered carefully because they can be useful to reduce heating requirements. In recent studies in Canada the increase of roof albedo from 0.2 to 0.8 showed a maximum air temperature decrease of about 1 °C by implementing cool roofs [18]. On the other hand depending on the use of the building internal heat gains might be so high that air conditioning may be required throughout the year. Various studies concerning cool materials in temperate climatic conditions can be found in the literature [19–22]. The application of cool roofs in a building situated in London [23] showed that although thermal comfort can be improved by an average of 2.5 °C operative temperature during summer, in the case of

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http://dx.doi.org/10.1016/j.enbuild.2013.10.024

temperate climates the type, operation and thermal characteristics of the building should be considered carefully to determine potential benefits of the application of cool roof technology.

Innovative materials for buildings and outdoor spaces have been developed and tested [24–28]. Their durability, ageing features, UV degradation, and contribution to energy efficiency impact are still under investigation. Such materials include innovative cool coatings, phase change materials, chromotropic and photocatalytic coatings with self-cleaning functionalities, nano-composites etc. [28–31]. Innovative materials will have a significant impact on the built environment in the near future and their effects should be sufficiently well understood in the context of energy conservation and environmental impact.

To this end the aim of the present study is to reveal the contribution of an innovative cool fluorocarbon coating in the reduction of energy demand for cooling when is applied in an industrial building with increased heat gains under temperate climatic conditions. In order to serve the aforementioned objective a series of laboratory and field experiments are performed. The laboratory experiments involve the measurements of the optical properties before and after accelerating weathering for the specific coating in comparison with other coatings. The laboratory testing is followed by field application of the specific coating in an industrial building in Netherlands in order to assess contribution to the reduction of energy demand the actual albedo versus the laboratory testing as well as its contribution to the reduction of energy demand. The paper is structured in five more sections. Section 2 includes the laboratory testing activities while Section 3 describes the field testing performed in the real building. The energy performance of the cool material is assessed in Section 5 while Section 6 summarises the main conclusions and highlights further developments needed.

2. Materials and methods

The studied coating is a tetrafluoroethylene monomer fluorocarbon coating (FC coating) in a water-borne formula which is applied on a cement tile (7 cm × 7 cm) and on an aluminium substrate (10 cm × 10 cm). Together with the specific coating a series of other coatings are measured for comparison purposes. The coatings are:

- S1: methyl methacrylate coating.
- S2: water based elastomeric coating.
- S3: polyurethane coating.
- S4: fluorocarbon coating in a water-borne formula (FC Coating).

The characteristics of coatings are tabulated in Table 1. Each substrate is coated at a thickness of approximately 110 μm.

This study includes for each sample:

- Spectral reflectance measurements over the spectrum 300–2500 nm (UV–vis–NIR).
- Calculation of the solar reflectance (%).
- Calculation of the solar reflectance index (SRI).
- Measurement of the infrared emittance.
- Calculation of maximum surface temperature.
- Accelerated ageing of the samples in an accelerated ageing xenon test chamber.

3. Laboratory testing of the samples

3.1. Accelerated weathering

Accelerated ageing of all samples is performed in an accelerated ageing xenon test chamber (Q-SUN, Xe-3HS) for a 60 days period in a 24 h basis according to the specifications and requirements of ISO 11341 [32].

Xenon arc lamp test chamber tests materials for photostability by exposing them to ultraviolet, visible and infrared radiation. It produces the most realistic simulation of full spectrum sunlight using filtered xenon arc light.

With a nominal cut-on of 295 nm, the daylight filter used, provides the most accurate spectral match with direct sunlight. The filter is recommended for the best correlation between the accelerated ageing test chamber and natural outdoor exposures and conforms to the spectral requirements of ISO 4892, ISO 11341, ASTM G155, SAE J1960 and SAE J2527.

The test chamber is equipped with a precision light control system which allows the choice of the desired level of irradiance. Irradiance is monitored and controlled at 340 nm.

Temperature monitoring and control is performed by a black panel temperature sensor which controls the specimen's surface temperature and simultaneously by the chamber air temperature control to give the ultimate determination of the specimen temperature. The effects of outdoor moisture are simulated by direct, pure water spray and by relative humidity control. The samples before and after weathering are depicted in Fig. 1.

3.2. Solar reflectance

The spectral reflectance of the samples is measured in the range of 300–2500 nm. The measurements for the solar spectral reflectance are conducted according to the ASTM Standard E903-96 by using a UV/vis/NIR spectrophotometer (Varian, Carry 5000) fitted with a 150 mm diameter, integrating sphere (Labsphere, DRA 2500) that collects both specular and diffuse radiation. The reference standard reflectance material used for the measurement was a PTFE plate (Labsphere) [33,34]. Additionally the solar reflectance in the ultraviolet (UV: 300–400 nm), the visible (vis: 400–700 nm) and the near infrared (NIR: 700–2500 nm) part of the electromagnetic spectrum is calculated. The calculated values of solar reflectance are shown in Table 2.

The solar reflectance for all the tested samples was high before the accelerated ageing. All samples were characterised by high reflectance values in the visible (0.94–0.97) and the near infrared part of the spectrum (0.87–0.88). Moreover all samples have strong absorption (0.08–0.09) in the UV range (300–400 nm).

After the accelerated ageing the solar reflectance values for all the samples have been reduced by 0.02, with the exception of Sample S1 for which the smallest reduction has been measured. Reflectance values in the near infrared part of the spectrum were stable for samples S2 and S4 and were reduced for the rest of the samples.

3.3. Measurement of the infrared emittance

The infrared emittance (e) specifies how well a surface radiates energy away from itself as compared with a black body operating at the same temperature. The measurements for the infrared emittance were conducted according to the ASTM Standard E408-71 (2002) by using the Emissometer Model AE (Devices & Services). The results of the infrared emittance measurements are presented in Table 3. The samples infrared emmitance values was slightly decreased. The largest reduction was measured for sample S3 (0.05). The smallest reduction was measured for samples S1 (methyl methacrylate) and S4.