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Review

# Thermal performance of reflective materials applied to exterior building components—A review

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ABSTRACT

Reflective materials applied to opaque building components are becoming increasingly important because of their benefits in terms of thermal comfort and energy savings. Because of their optical properties, reflective materials stay cooler than standard materials under the same conditions; therefore, they are also known as cool materials. This paper presents a review on the state of the art of the application of reflective materials on buildings' walls and roof. The thermal performance of these materials has been analyzed using different methodologies. Thus, the reported studies can be classified into seven categories: roof as a component, test cells, computational fluid dynamics, building simulation, monitored buildings, calibrated simulation, and mesoscale modeling. The paper describes the results obtained by means of these methodologies, the main characteristics of the models and, when available, the optical properties of the standard and cool materials.



**Contents**



## 1. Introduction

Buildings are complex systems that consume many resources (i.e. water, materials, energy, etc.) and large generators of different types of waste and pollution. Buildings account for 40% of the world's primary energy consumption and are responsible for about one-third of global $CO_2$ emissions [1]. One of the major causes of energy consumption in buildings is air conditioning. Many factors influence the indoor thermal environment, and therefore the energy consumption in air-conditioned buildings; the climatic conditions, the construction materials, the area of opaque and semi-transparent parts, the orientation, etc. Although all components of the building envelope are in contact with the external environment, the roof is the component with the highest temperature fluctuations. The impact of solar radiation on clear days, the loss of heat in the infrared during the night, and the rain, all affect the roof more than any other component of the building [2]. As mentioned by Nahar et al. [3], a roof can contribute with up to 50% of the thermal load for buildings in hot climates. Hence, this component plays an important role in the thermal performance of buildings.

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**Nomenclature**

| | |
|---|---|
| $A$ | area, $m^2$ |
| $U$ | thermal transmittance, $W\,m^{-2}\,K^{-1}$ |
| *Greek symbols* | |
| $\rho$ | solar reflectance |
| $\varepsilon$ | thermal emmitance |

One way to reduce the influence of the roof into the heat gains is to implement passive measures. Important research has been conducted in the field of passive cooling for roofs. According to Sanjai and Chand [4], the passive cooling techniques can be classified in architectural methods and non-architectural methods (Fig. 1). The architectural methods are related to the configuration and the roof geometry that contribute to the reduction of heat gains. These methods are usually applied in the construction stage of the buildings. For example, the domed roofs are popular in the vernacular architecture of the Middle East and Africa due to their thermal advantages; the thermal radiation over the inhabitants tends to be diminished, and if they have an opening at the crown of the dome, it permits the escape of heated air causing buoyancy-induced ventilation [4,5].

On the other hand, the non-architectural methods can be used independently of the roof geometry. These passive techniques are becoming important since they can be implemented in existing buildings. The transmission barriers are materials that prevent the inward of heat flow of the roof due to its low thermal conductivity. These materials are installed in either the interior or the exterior of the roofs; in addition, they can be used in walls. The wetted roofs use the evaporative cooling to diminish the surface temperatures. A wetted roof can have a layer of accumulated water or it can be sprayed continuously, another type is the use of wetted gunny bags [3,6]. A reflective or cool roof is a conventional roof with a solar reflective material on the exterior surface. The high solar reflectance ($\rho$) and thermal emittance ($\varepsilon$) of the coating conserve the surface cooler (with a lower temperature) than conventional roofs under the same conditions. This measure is the easiest to apply since the optical properties can be controlled just by acting on the surface of the roof, generally changing the color or by using high reflective materials (cool materials) [7].

A cool roof is not a new concept; travel photos from the Mediterranean and Middle East often show a landscape of homes with white roofs and walls. These are in fact cool roofs, and have been a common architectural element for thousands of years [8]. However, this simple technique has often been ignored in modern buildings in other locations.

An ordinary white material reflects most of the solar energy in the visible spectrum (0.4–0.7 μm); this material clearly will keep a component cooler than a non-painted one. However, a lot of research has been performed last decades to develop cool white materials that reflect solar radiation in both, the visible and the infrared spectrum (0.4–2.5 μm) [9–13]. These materials may have very high values of solar reflectance (up to 0.9) and can stay 10–25 °C cooler than standard materials [14–16]. Most common cool white materials are liquid applied coatings, but single ply membranes are also available. On the other hand, as a white pitched roof or white walls may lead glare problems, in recent years, cool colored materials have been developed [17–19]. These materials have the same color than common materials, but a higher reflectance in the infrared spectrum (0.7–2.5 μm). Cool colored materials can lead to surface temperature reductions between 5 and 13 °C with respect to their matching conventional colors [20,21].

Decreasing the temperature of opaque components reduces the heat flow into the building, leading to energy savings in air conditioned buildings and comfort improvements in non-cooled ones. Many studies have been performed over the years to analyze the thermal performance of reflective materials applied to exterior building components, being most commonly evaluated on roofs. Haberl and Cho [22] presented a literature review about cooling energy savings from cool roofs based on twenty-seven articles. They reported that cooling energy savings in residential and commercial buildings varies from 2% to 44% and averaged about 20%. The literature indicated that the peak cooling energy savings from cool roofs are between 3% and 35%, which depends on ceiling insulation levels, duct placement and attic configuration. However, these findings are exclusively for typical US buildings.

This article presents the state of the art of the research carried out internationally with regard to the thermal performance of reflective materials applied to building components. Different methodologies have been used to study the potential of reflective materials to improve thermal comfort and to reduce energy consumption in buildings. Therefore, the review is divided into seven sections: roof as a component, test cells, computational fluid dynamics, building simulation, monitored buildings, calibrated simulation, and mesoscale modeling. In each section, a summary table describes the results, the characteristics of the models, the location of the study and, when available, the optical properties of the standard and cool materials are also presented.

## 2. Roof as a component

The studies presented in the following section consider the roof as a single component. We present theoretical and experimental works where the roof heat transfer is analyzed. Theoretical studies are based on either steady state or transient models. Experimental studies are carried out outdoors or indoors. In the first case, the samples are exposed to the sunlight, while in the second, halogen lamps are used instead.

Stationary methods were used to estimate the total heat gain of roofs during a day. Reagan and Acklam [23] reported one of the first studies. They calculated the daily average heat gain using the Total Equivalent Temperature Difference (TETD) method for a roof in Tucson, Arizona. When the roof color was changed from dark to light, the heat gain was reduced up to 50% for poorly and well insulated roofs. Assem [24] estimated the thermal transmittance ($U$-value) of walls and roofs typically used in Kuwait with the TETD method. A series of correlations based on the solar reflectance were developed. When the roof reflectance was increased, the daily heat gain was reduced up to 42%. Another analysis was presented by Suehrcke et al. [25]. The authors derived an equation to estimate the heat gain of dark and light colored roofs. For north Australia, the derived equation suggested that a light-colored roof had about 30% lower daily heat gain than a dark-colored one.

Four dynamic analyses of the transient heat transfer in roofs were performed. In these studies, the climatic data were time varying and the interior air temperature was considered constant as a result of using an air conditioner. For instance, Granja and Labaki [26] studied the influence of the external color in a flat roof for a summer design day of Campinas, Brazil. They used Fourier analysis to solve the heat conduction equation. When the roof had a low thermal resistance (thickness), the change of color from gray to white caused a heat flux reduction up to 74 W/$m^2$. In contrast, for thicknesses greater than 15 cm, the roof was not influenced for the change of the color. A numerical study conducted by Oliveira et al. [27] estimated the heat flow in a concrete roof. Low and high solar reflectance conditions were evaluated for 14 cities in Brazil. Compared to the conventional roof, the reflective roof resulted in