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Thermal-energy and environmental impact of cool clay tiles for residential buildings in Italy

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Abstract

Sustainable solutions for energy saving in buildings are assuming increasing interest both in the research and the industrial community. In this view, cool roof systems demonstrated to be interesting and effective solutions which role in energy saving for cooling and mitigating local and global warming is already acknowledged. In these recent years, several studies were carried out in order to quantify their thermal-energy effect with varying boundary conditions, while global climate analytical models were proposed with the purpose to evaluate the effect of high albedo solutions in terms of radiative forcing and CO_{2eq} offset. This work concerns the combined analysis of thermal-energy and environmental effect of cool roof (high albedo) clay tiles with low visual impact, specifically optimized in order to preserve traditional residential buildings. In particular, dynamic simulation models and field monitoring of a real residential village were developed and the effect of such tiles is analyzed in terms of energy saving for cooling and of CO_{2eq} avoided emissions due to the energy efficient intervention, coupled with the effect in climate change mitigation. This aspect is specifically considered by applying an analytical method elaborated in previous works, where the effect of high albedo surfaces in terms of CO_{2eq} offset is quantified with varying orientation, inclination, solar reflectance and geographical details. The combined analysis showed how an overall annual CO2 emissions' offset is achievable by coupling single-building and global assessment methodologies. In particular, the energy saving contribution saved around 141 tonnes of CO_{2eq} per year, and the global warming analytical model showed that the albedo increase allowed to offset about 772 tonnes of CO_{2eq} per year. This prototypical study showed how local energy analysis should be coupled to global analysis in order to have an exhaustive view of building retrofit strategies' sustainability.

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1. Introduction

The total energy requirement of the construction sector represents more than the 40% of the whole energy need and the economic-industrial development of several countries produced important increase of energy need [1]. The increase of residential consumption is even more relevant [1] and in fast developing countries the construction sector is responsible for more than 50% of the total electricity demand [2]. In this panorama, important research and innovation strategies were studied with the final purpose to reduce building energy requirement and the environmental impact of constructions [3-4]. Several interesting research efforts were focused on the optimization of building envelope solar reflectance, in order to reduce the overheating of buildings and the relative energy consumption for cooling. These high reflectance materials were commonly defined as “cool” materials, having a non-negligible passive cooling effect with varying climate conditions, building architecture and occupancy, as demonstrated by recent research contributions [4-5]. In this view, several case studies were monitored in order to quantify the real energy saving contribution and indoor thermal comfort optimization due to cool envelopes. Such experiments were carried out even in relatively cold climate conditions such as Northern Europe and Canada [6-7]. All these works showed an overall annual benefit produced by cool roofs with negligible, or relatively minor, winter penalties. After the demonstration of such effect, other studies were carried out in order to study weathering and aging phenomena affecting cool materials such as paintings or membranes [8-9]. Since the important role of the environmental conditions affecting the durability of such materials, key researches are in progress in order to develop experimental benches to simulate this forcing with varying weather and boundary stresses such as pollution. Sprawling the boundary from the single building to the urban scale, high solar reflectance (albedo) solutions were acknowledged to have an interesting effect in mitigating meso-climate overheating effects, such as urban heat island [10-11]. Also, the same high albedo surfaces were acknowledged to contribute to global warming mitigation [12-13]. In this view, consistent models were developed in order to estimate the effect of high albedo surfaces exposed to solar radiation in terms of CO_{2eq} offset [12].

Albedo increase solutions, in fact, contribute to the reduction of the amount of energy absorbed by the Earth surface and, therefore, to mitigate global warming path imputable to anthropogenic sources [14]. Since this contribution is able to compensate the effect produced by the emission of greenhouse gases into the atmosphere, the implementation of high albedo surfaces exposed to solar radiation, e.g. cool roofs and paving, could be estimated in terms of CO_{2eq} offset. In this view, an innovative methodology was developed in order to estimate the CO_{2eq} abatement potential of highly solar reflective surfaces with varying geographical location of the site (latitude input parameter), weather conditions, slope and orientation of the surfaces, e.g. roofs and paving [12]. This analytical procedure could be applied for quantifying the further global environment benefit of high albedo roofs and paving exposed to solar radiation, as amount of CO_{2eq} emission offset potential. Additionally, the possibility to specify both geometry and location of surfaces, allow to quantify the mitigation potential of specific case study buildings or entire areas.

As previously mentioned, several key researches were carried out in order to identify each one of these effect, one at a time. This work is aimed at filling this gap in order to combine the single-building scale analysis to the global approach. Starting from previous research contributions about (i) cool roof innovative solutions, and (ii) the effect of high albedo surfaces exposed to solar radiation in terms of their potential in reducing global warming, this work is aimed at considering the combined energy and environmental effect of a cool roof clay tile specifically optimized to have a low visual impact, suitable for application in traditional architectures. To this aim, a real residential village located in central Italy was selected and three building categories were identified in order to allow the simplified numerical analysis of the energy performance of the village, with a focus on cooling electricity consumption. The effect of the high albedo tiles is firstly assessed by mean of energy saving potential in summer. Then this energy saving is equalized to the corresponding avoided CO_{2eq} emissions due to the reduction of electricity demand in