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On the thermal and visual pedestrians' perception about cool natural stones for urban paving: A field survey in summer conditions

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ABSTRACT

While cool materials are widely acknowledged for lowering surface and air temperatures, mitigating Urban Heat Island, reducing emissions imputable to active cooling systems in buildings, concerns arise about their impact on pedestrians' thermal and visual perception. These materials are typically applied on roofs, urban paving and building envelope: when the application is on non-usable spaces for pedestrians, it represents a win-win solution, since it decreases thermal stresses with no penalties for pedestrians. Instead, if the cool surface is installed over a passage area, glare and thermal radiative stress could affect pedestrians' comfort perception. In this work, a naturally cool, light colored stone is considered in the form of aggregates with varying grain size for cool roofing and paving application. Therefore, given its intrinsic passive cooling effect, this paper wants to experimentally investigate if such sustainable and cost effective material can create sensible thermal/visual discomfort perceived by pedestrians. To this aim, pedestrians' perception is investigated by means of in-situ survey and continuous monitoring in summer variable weather conditions, by taking into account several paving systems, i.e. grassland, asphalt, natural stones, and the investigated cool stone aggregates. The study demonstrated how in hot and sunny weather conditions, pedestrians prefer grassland, while asphalt is the least favorite material in any case. Cool gravel based surface does not produce thermal discomfort but it produces some visual discomfort due to glare issue, only in sunny weather conditions. In fact, variable weather conditions significantly affect pedestrians' sensitivity and their preference, also in the same summer season.

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1. Introduction

Global warming and climate change are two of the greatest challenges that this and future generations have to deal with, gaining increasing attention both from scientific community and public opinion. The Paris Climate Change Conference [1] has been recently held in order to address these concerns and find practical solutions to counteract such growing phenomena. Starting from 1750, increasing quantities of carbon dioxide (CO_2) have been emitted in the atmosphere due to fossil fuel combustion [2]: this fact was considered as responsible for a gradual warming of our Planet and, therefore, climate change phenomenon.

In urban environment, the Urban Heat Island (UHI) effect causes densely populated areas to reach higher temperatures than surrounding suburbs [3–6]. This phenomenon exacerbates thermal stress in urban areas, leading on its turn to higher HVAC systems utilization in summer and therefore increased greenhouse gases emissions (GHGs), thus accentuating the problem. UHI phenomenon causes many critical issues, by deteriorating urban living conditions up to increasing mortality rates, increasing the impact of heat waves phenomena [7]. Moreover, the trend for urban areas is of great growth, where the percentage of population living in urban areas, constituting today the 54% of total world population, is expected to reach up to 66.4% of total population in 2050: this percentage is even more impressive considering the forecast for population growth, equal to +2 billion of individuals, with respect to 2014, for 2050 [8]. UHI is generated by controllable and uncontrollable variables: for

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controllable variables, urban design and anthropogenic sources are considered, while uncontrolled variables are wind speed, cloud cover, seasonal and diurnal conditions as well as anticyclone conditions [9]. Urban design comprises elements such as sky view factor, height to width buildings' ratio, green areas and materials for the built environment. On its turn, population is responsible for anthropogenic heat and air pollutants released towards the environment. By controlling these variables, it is possible to mitigate the severity of UHI phenomenon [10], depending on local climate [11–15]. Therefore, many studies dealt with these challenges, by investigating urban morphology [16] and tailored materials able to reflect solar radiation thus reducing the absorbed and released heat, with the final aim of decreasing emissions, energy consumption, and improving outdoor as well as indoor thermal comfort conditions [17–19]. While in the case of new constructions and early stage design phases a large variety of interventions are still possible and relatively easy to be implemented, in consolidated and historical cities the use of specific new materials has been identified as a feasible and efficient method to counteract UHI [20]. Green urban areas [21,22] buildings' envelope or roofing [23–25], ponds and cool materials [26,27] as urban surfaces emerged as passive solutions [28] for improving both indoor and outdoor thermal comfort conditions. Cool materials in particular are characterized by high solar reflectance and high thermal emissivity, able to absorb less heat and emit it back to the sky when exposed to solar radiation, with respect to traditional non-cool materials. For these characteristics, cool roof and cool paving strategies have been analyzed by researchers and implemented into the built environment, permitting to achieve a threefold advantage. They i) reduce surface and air temperatures, with benefits both for indoor living spaces, i.e., lower heat loads into the building, and for outdoor areas, i.e., lower air temperatures and temperature peaks during hot season. They ii) mitigate UHI and they iii) mitigate climate change and global warming [19]. More in detail, cool paving and cool roof solutions consist in covering the chosen urban surface with these materials as finishing layer: cool roofs also bring the advantage of decreasing cooling loads during the hot season, improving occupants' thermal comfort, thus decreasing emissions. During winter, given the lower strength of solar radiation, the effect is relatively minor, thus it does not compromises significantly the annual energy performance [29]. While these passive solutions, such as cool surfaces or greenery, were demonstrated to be more efficient in lowering urban temperatures as paving than when applied on roofs [30], given the scarce availability of space on the ground in densely built urban areas, roofs' solutions are regarded as an effective way to mitigate UHI. Moreover, as above mentioned with respect to cool materials, the implementation of such strategies on the roof brings the advantage of reducing energy demand for cooling.

Considering urban areas and outdoor air temperatures researches, cool roofs and pavements are being studied by the scientific community for their capability to reduce anthropogenic urban overheating, consequently counteracting the overall UHI effect. Santamouris and colleagues [20] quantified ambient air temperature reduction brought by the implementation in Marousi area, Athens, of passive strategies such as cool paving for pavements and streets, which is equal to 3.4 K during the hot season. Confirming these results, Shahidan and colleagues [31] evaluated urban air temperature by means of in situ measurements and simulations, when vegetation and cool materials are employed in order to reduce peak temperature: the findings of this work quantify a reduction of 1.5 K.

Concerning specifically sustainable and innovative material science, by dedicating particular attention to natural materials, some of them were investigated for showing promising optic and thermal characteristics which are intrinsically suitable for cool roof or paving applications. Additionally, natural materials have the advantage of not involving harmful matters in assembly and disposal, and are usually less energy intensive [32]. In particular, considering cool materials, light colored stone in the form of aggregates has intrinsic high albedo and emittance [32], which are the key characteristics for maintaining lower surface temperatures when exposed to solar radiation. They are typically applied for buildings' vertical envelope or cool roof, reducing heat gains entering the building; or they can be used for urban paving, lowering surface and air temperatures [33]. Pisello and colleagues considered stone gravels with different grain sizes: they measured solar reflectance and albedo in the field, demonstrating to present increasing albedo with decreasing the grain size [34].

2. Motivation

Taking into account outdoor spaces characterized by cool materials, while there is a wide range of sophisticated studies about the analysis of outdoor thermal comfort and pedestrians' perception in different climates [11,35–37], thermal and visual effect of cool paving systems of pedestrian perception represents a key topic, needing further investigation. In fact, the extra-contribution in terms on reflected radiation of cool materials should be carefully studied, since it could also be responsible of glare effect and overheating local discomfort phenomena. The importance of visual perception assessment when considering outdoor comfort conditions for users is underlined by previous study [38].

Therefore, while optimizing the albedo of urban surfaces exposed to solar radiation, both these possible penalties should be controlled, for environmental comfort and public safety purpose. Of course, non-stepped cool roof surfaces represent a win-win solution since they lower surface and air temperatures, reduce heat gains through the building and the consequent cooling system emission, and mitigate UHI, without negatively affecting pedestrians' thermal and visual perception. However, the only roofing surface is often not able to counteract UHI, in particular in dense and tall buildings' districts. The effect of optimized solution for pavements needs to be experimentally studied and pedestrians' opinions need to be listened for optimizing outdoor environmental (both thermal and visual) quality in urban areas.

Consequently, the aim of this work is to evaluate pedestrians' perception with respect to cool, bright materials applied on horizontal urban surfaces, after verifying their promising application for urban cooling purpose and local availability as natural material. The study is carried out by means of a field survey and statistical analysis of pedestrians' perception with varying weather conditions in different summer conditions. In fact, summer season is the key period when pedestrians are used to spend more time in outdoors and when they are mostly affected by local overheating phenomena in dense anthropic areas [39]. Additionally, the comparison with more common paving surfaces such as grassland and asphalt is performed in terms again of both visual and thermal pedestrians' perception. The materials chosen for the analysis are with light color natural gravels, extremely low cost, locally available in many regions of the world, with intrinsic appropriate cool characteristics [34], already demonstrated by in-lab and in-situ experiments. The authors intend to investigate human perception of this smart and relatively simple solution by cross-checking in field surveys' results with in situ measured weather data and interviewees' personal characteristics, in order to identify the role of meteorological boundary and to permit an exhaustive and complete, unbiased evaluation.

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