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How high albedo and traditional buildings' materials and vegetation affect the quality of urban microclimate. A case study

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ABSTRACT

The wellbeing and life quality also depend on the climatic conditions of the surrounding environment. In this case study the focus is on those interventions that can be performed, especially on enclosed urban contexts, to control the thermal environment. It pays attention on the effect of the vegetation and high albedo materials characterizing horizontal and vertical boundaries of the site and the Cloister by Giuliano da Sangallo, a historical site in Rome, is taken as case study. The model of the site was simulated with the software ENVI-met and it was verified thanks to a measurement campaign in situ. Five scenarios with different vertical and horizontal materials of the present buildings were simulated together with an analysis of the variations of physical quantities (air temperature, mean radiant temperature, relative humidity, wind speed) affecting the perception of environmental comfort (calculated through the Predicted Mean Vote).

The result is that in those areas characterized by a Mediterranean climate, where the summer months with high temperatures must be mitigated, the vegetation can be a significant benefit to the environment, and high albedo materials can ease the thermal load of the buildings with a higher thermal stress for the pedestrians.

1. Introduction

Examining the urban microclimate is really important in order to establish the life quality of an urban context, which in turn affects the image of a city. Since the ancient times, suitable public spaces were designed to attract as many people as possible and make them as more livable spaces [1]. During the years the techniques used for these purposes improved, but only today we have the sophisticated means for an optimized designing of outdoor spaces. In other words it can be possible to improve the quality of an outdoor public space by taking care of those factors influencing the thermohygrometric comfort [2–6]: actually, spaces characterized by a discomfort tend to be avoided or poorly exploited.

It should be kept in mind that, recently, the chaotic development of cities led to different and unwanted microclimatic changes which in turn determined that temperatures, in the urban setting, were higher than those characterizing the surrounding rural environment. Different studies showed that thermophysical properties of urban surfaces and buildings' envelopes affect the microclimate and can lead to a rise in air temperature and mean radiant temperature values [7,8] and to a variation in thermal-energy performances [9].

This is why outdoor urban areas must be planned by considering, where necessary, the right mitigation strategies. Some of these strategies, partially affecting one another, are: the use of high albedo surfaces [10,11], evaporation from porous surfaces [12,13], evaporation from ground-level water surfaces [14] and roof ponds [15], vegetated surfaces [16], rooftop gardens [17], and trees [11,18].

This paper, through the analysis of a case study concerning the Cloister of San Peter in Chains (inside the Faculty of Engineering of the Sapienza University of Rome), examines how those mitigation strategies affect the microclimate and the outdoor thermal comfort. In particular, through the analysis of different configurations with different solutions for the vertical and horizontal boundaries

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of the site, the influence of innovative high albedo materials and vegetation is examined.

The innovative materials studied were developed to optimize the energy needs of the buildings and it is important to analyze how they affect the outdoor thermal comfort of the pedestrians. The solutions chosen are also determined by the historical/architectonic importance of the urban context, characterized by an enclosed geometric configuration.

Finally the selected performance metric is the comfort sensation of a pedestrian standing in the Cloister and this sensation is estimated through the PMV (Predicted Mean Vote) [19].

1.1. Mitigation strategies and microclimate

Before applying the microclimate mitigation strategies through different solutions for the vertical and horizontal boundaries of the site, what was reported in the previous studies were taken into consideration. This paragraph summarizes the results of some studies concerning the exertion of high albedo materials and the presence of vegetation and how they affect the microclimate.

In particular high albedo materials leads to lower temperatures of the surfaces exposed to solar radiation than those characterized by more traditional materials, thus having a lower temperature characterizing the environment [20].

From this point of view it is important to consider that different studies [21,22] showed how the most commonly used materials for urban spaces, such as asphalt, brick, and stone pavements (with a low albedo: 0.05, 0.20, and 0.40 respectively) intensify the urban heat island phenomenon. Other studies [23,24] showed how the use of low albedo materials with high heat capacity determine an increase in the temperature difference between the city and the surrounding areas, during the night in particular. Another study [25] compared then 93 materials used for outdoor flooring noticing that the albedo is mainly affected by the color of the element examined, the surface texture (roughness), and the type of material. The conclusions reached by this study show that flat and smooth tiles made of marble or stone present a higher albedo, with respect to similar tiles made of concrete or granite.

A high albedo leads to lower surface temperatures characterizing the exterior finish of the buildings leading to lower temperatures in indoor environments [26], but on the other hand it can affect in a negative way the psychophysical wellbeing of the pedestrians [27–29]. Hence the goal of this study is to consider the influence of the albedo on the outdoor thermal comfort too. The existing bibliography shows how a study [30] carried out in Shanghai revealed that if the albedo of the exterior surfaces increases by 0.4, the conditions of the outdoor comfort get worse with a rise of 5–7 °C of the PET index. On the other hand, another study [31] showed how, in Portland, the use of a white material (with an albedo of 0.91) determines an increase of the globe temperature and mean radiant temperature of 0.9 K and 2.9 K respectively and a drop in temperature of indoor environments of 1.3 K. It should not be forgotten, as the study [32] points out, that the use of high albedo materials on exterior and opposite walls determines an increase of the cooling load due to the reflected solar radiation inside the environments through the windows.

For what concerns the effect of the vegetation on the microclimate, the existing bibliography shows some studies which focused on this issue: the first studies [33] were carried out in the early nineteenth century. Then, more than one study [34–37] reported how, contrary to the urban heat island, the park cool island can lead to a drop in air temperature of 3–4 °C during the summer. In fact vegetation makes the environment cooler through evapotranspiration phenomena which are the result of evaporation (from the earth's surface) and transpiration (of the vegetation) phenomena [38–40]; moreover a surface with some vegetation reflects a higher amount of solar radiation than one characterized by asphalt [41] and collects a lower amount of heat [36,42]. Another study [43] quantified the decrease of the air temperature determined by the evaporation processes connected to the grassy and humid soil compared to a similar surface with exposed soil at 6 °C; this study also revealed that on a sunny day, a 1 m^2 of grass absorbs 12 MJ. A further benefit of having green surfaces (green roofs for example) is the effect that they have on the energy needs for the comfort of indoor environments [44]. In accordance with some studies [45–47], trees and shrubs placed next to a building determine a decrease of 15–35% of the costs of the air conditioning (reducing the annual cooling load of 10%). Moreover a roof characterized by a black surface exposed to solar radiation during the summer can be as much as 50 °C hotter than a roof covered with vegetation with a similar position [48], leading to a rise in air temperature.

Fig. 1. Present configuration of the Cloister of the faculty of engineering of "Sapienza" University.

Such rise in temperature has an influence on energy requirements as well [49]. A study [50] showed that during the summer, the cooling load of a building, characterized by the presence of offices, placed in the metropolitan area of Hangzhou, China, would increase by 10.8% due to a rise in air temperature of 0.5 K.

Other studies [10] reported that a rise in air temperature of 1 K leads to an increase of 2–4% of electric consumption in the cities of the United States and that in urban areas, the 5–10% of electric energy is consumed to cool the buildings thus counterbalancing an increase in the air temperature of 0.5–3.0 K.

Finally, a study carried out in the Mediterranean area [51] showed that during the last 40 years, in a classic building for offices in Greece, occurred a decrease in the heating load of about 1 kWh/m^2 per decade, whereas the cooling load increased by about 5 kWh/m^2 per decade.

2. Case study

The case study examined was the Cloister (Fig. 1) placed next to San Peter in Chains church, in the historic centre of Rome. The city is characterized by a typical Mediterranean climate, that is, mild and warm temperatures during the spring and fall. Most rainfall is seen in spring and fall, during the months of November and April in particular. Summer season is usually hot, humid, and characterized by low precipitation, whereas winter tends to be mild and wet with isolated phenomena of low temperatures and snowfall. According to Köppen's classification, such weather belongs to the Csa category [52].

The Cloister is part of the complex which nowadays represents the Faculty of Engineering of "Sapienza" University of Rome; its location is right in the historic centre, near the Colosseum. Its