Urban Heat Island Mitigation Strategies

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An experimental and numerical investigation of the climatic conditions in a university area in Rome was achieved, along with evaluating the occurrence of the UHI phenomenon. A preliminary analysis of the UHI phenomenon was carried out and an average urban heat island index equal to 1.14 °C was identified, with a peak value equal to 5.9 °C. This preliminary assessment led to a more detailed investigation using a simulation code. A calibrated model was generated through the software ENVI-met and different mitigation strategies were tested, in order to reduce the overheating of the area. So, eight different scenarios were compared with the actual state, testing the effects of trees, cool pavements and lawn, as well as considering combinations among them.

The analysis of this case study and the performed simulations led to the conclusion that careful choices must be made during the design phase of an area, even when it comes to universities. More in general, objectives and priorities in the design phase should concern not only buildings but also external areas, but this conceptual paradigm needs to be also applied for university areas. Therefore, during the requalification of urban areas involving both buildings and outdoor areas, different skills must be combined and applied.

Keywords: university areas ; overheating ; urban heat island ; mitigation strategies ; ENVI-met ; model calibration

1. Urban Heat Island

Human comfort and buildings' energy performance are influenced by the growth of urban areas, where constructions and infrastructures have replaced open land and vegetation, with unavoidable landscape change.

Modifications of towns led to the well-known urban heat island (UHI) phenomenon, with higher air temperatures in densely built areas than rural ones. Differences in temperature can vary between 1 °C and 3 °C in cities where a million or more people live [1].

The UHI phenomenon has been investigated since the 19th century [2] and it is currently studied by the scientific community, which is focused on identifying mitigation strategies and effects that the UHI implies [3].

The UHI effects are influenced by various local, regional and global variables strictly correlated to the global climate change. Climate change improve the stress on urban environments through the increase of heat waves, threatening the health of all people, from old to young. Furthermore, climate change rises the frequency and intensity of droughts and inland floods threatening water supplies, and the enhanced sea level and storm surges affecting people and infrastructures [4]. At the same time, human activities are one of the main causes of the increasing of greenhouse gas emissions that contribute to increase the global climate change and, as in a loop, it is one of the reasons why the urban temperatures are rising. Urban temperature projections are required for the development of city-specific climate change mitigation policies despite the non-stationary nature of UHIs over time [5]. Urban environments' quality in cities are vulnerable to the effects of climate change and, at the same time, they play a crucial role in its mitigation.

The future urbanization until the 2070s was investigated by Adachi et al. [6], finding that the increase in the surface air temperature from 1990s to 2070s will be about 2.0 °C as a result of global climate changes, and about 0.5 °C as a result of urbanization. McCarthy et al. [7] affirms that the presence of the urban heat island has a significant impact on the frequency of extreme high temperatures both in present and future climates, and it will exacerbate the impact of climate change on the urban population. Therefore, climate simulations have an important role to investigate the future warming due to UHIs' effects [8][9], and simulation on local climate conditions have an important role in order to evaluate the effectiveness of mitigation strategies.

Several investigations have been achieved all over the world, demonstrating that UHI is a current problem, able to significantly influence local microclimate, determining high temperatures, with subsequent negative influences on human comfort, contributing to human diseases and health risks [10][11]. Moreover, the urban heat island phenomenon, due to persistent high temperatures, determines impacts also related to buildings' energy consumptions, with higher cooling energy demands [12][13]. Even though UHI is usually related to big cities (characterized by large paved surfaces and millions of inhabitants), recent studies in literature show that even small towns (characterized by a few hundred thousand inhabitants) can be affected by this phenomenon [14].

For this reason, examining and investigating the urban heat island phenomenon is considered a key point by researchers all over the world, taking into account both causes and effects. Besides, it is fundamental in finding effective mitigation strategies and analyzing the best solutions, among which are green roofs, increased vegetation, cool materials and water bodies [15][16]

2. Some Mitigation Strategies

The relevance that the scientific community attributes to this topic is demonstrated by many scientific works available on search engines, such as ScienceDirect—in 2019 alone, more than 500 studies, related to the UHI mitigation strategies, were published. Some of them are discussed in the following.

Farhadi et al. [17] investigated different solutions for the UHI mitigation in Tehran. In particular, the authors analyzed the effects of urban vegetation on the street and roofs, high albedo surfaces' installation and the orientation of buildings by means of numerical models, generated with ENVI-met software. The authors affirmed that proper urban planning could mitigate the UHI, in particular for new sustainable developments, while thermal comfort improvements can be reached by increasing the percentage of urban vegetation.

Taking into account the neighborhood scale, Taleghani et al. [18] focused on the effect of mitigation solutions on the surface energy balance, analyzing the influence of four strategies, based on green roof, cool roof, additional trees, and cool pavement. The authors found that cool pavements led to the highest reductions in net radiation, with a temperature reduction equal to 2 °C in the early afternoon.

Imran et al. [19] proposed a study for evaluating the efficacy of urban vegetation covers such as mixed forest, combination of mixed forest and grasslands, and combination of mixed shrublands and grasslands for decreasing the UHI effects in the city of Melbourne. The analysis was performed using simulations performed through the Weather Research and Forecasting model coupled with the Single Layer Urban Canopy Model. The authors obtained temperature reductions ranging between 0.4 °C and 3.7 °C. However, the limitation of this study is related to the fact that direct interactions between vegetation and urban surfaces are not accounted for in the proposed model.

In his study, Bao-Jie He [20] proposed a new concept of Green Building, suggesting the idea of Green Building-based UHI Mitigation system, or Zero UHI impact building, aiming to reach the zero-heat impact on surrounding environments by means of sensibly designing structures, or depending on innovative solutions for removing the excessive heat.

A review related to the mitigation strategies for improving the thermal environment and comfort in urban areas was proposed by Lai et al. [21]. In particular, the mechanisms and cooling effects of some major mitigation strategies (urban geometry change, increased vegetation, cool surface installation and water bodies' use) allowed to find a median reduction of the outdoor air temperature equal to 2.1 °C, 2.0 °C, 1.9 °C, and 1.8 °C, respectively.

Finally, taking into account the raising public awareness about the UHI phenomenon, Zhang et al. [22] empirically analyzed the will of Beijing inhabitants to pay for the benefits deriving from green roofs for mitigating the urban heat island effects. The data were obtained from a valuation survey characterized by many zero responses. This paper advises that improving government credibility is a key factor in promoting public participation in mitigating urban heat island effect.

The potential effects of mitigation techniques and the assessment of the effects of the UHI are widely investigated through the dynamic simulation tool ENVI-met, developed by the Ruhr University of Bochum (Universitätsstraße 150, 44801 Bochum, Germany) [23]. The software was released in 1998, with a rapid growth in the number of authors who have used this tool for their scientific works, over the past decade [24]. In September 2020, on the Scopus database, about 556 papers were published using the ENVI-met tool of which 380 were published in international scientific journals. The majority of these papers focused on the assessment of the performance of the mitigation techniques. Researchers used this tool for simulating the thermo-fluid dynamic condition of urban areas, assessing the influences of urban vegetation, cool materials, water fountains, pollutant sources, geometry and distribution of buildings and roads. Several scientific papers investigated the effect of various urban greening on the outdoor air temperature [25][26][27][28]. Morakinyo and Lam [29] generated a model of an urban canyon to simulate the influence of different tree configurations. Wang and Zacharias [30] observed that the use of urban greening and permeable soils on roads can lead to a decrease in air temperature of about 0.5–1 °C. Furthermore, many researchers used the ENVI-met software for assessing the effects of cool materials

[31][32][33]. Chen et al. [34] found that an increased number of trees and higher albedo are more effective compared to green roofs in reducing summer potential temperatures at street level. Yuan et al. [35] simulated, through the ENVI-met tool, six scenarios varying the urban albedo and the urban greening in order to find the best match for a new residential area in Osaka.

Several investigations were done to evaluate the potential for urban overheating and mitigation in different areas of the world. However, not many studies on university campuses have been conducted, especially in Italy. This study focuses on university areas, analyzing the thermo-fluid dynamic condition in a recently renewed area of the Roma TRE University, placed in Rome (Italy). Roma TRE University is a young Italian campus, characterized by many buildings. Recently, the Engineering Department area, placed in a central area of the city, was renewed and the ex-towing tank building was re-designed, aiming at high performance. As mentioned before, the neighboring areas were also re-designed, leading to the construction of large paved surfaces characterized by high temperatures during summer. So, a methodological approach was here proposed and applied in order to generate a calibrated model by means of ENVI-met code and to test the influence of different mitigation strategies, represented by greenery, cool materials and canopy.

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