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Using cool pavements to mitigate urban temperatures in a case study of Rome (Italy)

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Abstract

The urban density and the design of built and natural environments of cities play a crucial role in defining sustainable patterns. Urban heat islands (UHI) are phenomena tightly associated with the development of cities and urban expansion. Its effect is defined as the increase of the urban air temperature compared to surrounding rural areas. One of the main technology aimed at reducing the urban air temperature is the adoption of cool materials. As a matter of fact, the increasing of solar reflectance of urban materials can lead to reduce the built surface temperatures and mitigate the urban heat island intensity. Its features have vast impacts and implications on energy efficiency, environment and at last on human comfort and health. Measured temperatures were used to calibrate a model of a densely populated neighborhood in Rome inputted in ENVI-met software. The actual temperature field was evaluated in comparison with proposed areas consisting in the adoption of high albedo pavements application. Simulation results showed a significant reduction of air temperature closely correlated with the road solar reflectance.

Keywords: urban heat island; validation model; ENVI-met; urban requalification; microclimate countermeasures; cool pavements

1. Introduction

The well-being and quality of life depends on the climatic conditions of the urban environment. This has a great importance due to the fact that about 50 % of the world’s population lives in urban areas [1–3]. This is why it is

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necessary to study the features of the local urban climate. Locally, the presence of an urban area changes the air temperature and humidity, the profile and the structure of the wind circulation schemes [4]. It is the phenomenon of the so-called urban heat island (UHI), which is the effect defined as the increase of the urban air temperature compared to surrounding rural areas [5]. The high rate of urbanization will lead to a bigger exposition to the heat island phenomenon. It follows that the district heating generated from the heat island effect in the city has a very significant impact on human life. It increases the consumption of energy for summer cooling, it reduces the levels of comfort, it increases the concentration of pollution, threatens human health and affects the urban economy. Another cause that concerns the formation of urban heat island is linked to the geometric aspects. As a matter of fact, tall buildings provide bigger surfaces for the absorption of solar radiation that leads to an increase of cooling demand: This phenomenon takes the name of "urban canyon effect". Another consequence produced by buildings is the obstacle to the wind that inhibits cooling by natural convection [6–20]. Every year European projects are aimed at studying the urban climate of the cities, in order to support the population to the climate change. Some of these projects are related to the urban heat island mitigation techniques such as the use of cool materials. These materials have a high reflectance to solar radiation with a high coefficient of emissivity. Low absorption of solar radiation and high infrared emission minimize the surface temperature of these materials, thus decreasing the amount of heat released into the atmosphere during the nighttime and the building cooling demand [21–29].

This study aimed to improve the thermal comfort of a Roman district: Flaminio. After experimental and numerical analysis steps of the area, cool materials was implemented in order to mitigate the urban heat island effect.

2. Methodology

The work consists of the following steps, such as:

- Measurement and analysis of thermohygrometric conditions in the area through the use of a psychrometer;
- Modelling of the area through ENVI-met 4.0 and validation step with experimental data;
- Analysis of the cool material effects from the current situation (ante-operam) to modify area (post-operam).

3. Case study

The area chosen for the city of Rome is an urban site in Flaminio area. In detail, the measures undertaken in this study were conducted in the urban canyon represented by the blue rectangle in Fig. 1(a). The case study is a zone called “Flaminio District” placed in Rome at latitude 41°54'39"24 N and longitude 12°28'54"48 E. The “Flaminio District” enclosed in the yellow line (Fig. 1(a)) is an area of about 0.218 km^2. The study area is located in the north of the city and north-west of the Tiber River. The analysed area are grouped in the following building categories: Historical buildings, condominiums about 70’s, sheds for industrial use and some modern buildings.

The area taken into account is about 735,000 m^2, as shown in Fig. 1 and hereinafter referred as ante-operam. It is characterized by vegetation along the streets and around the river as shown in Fig. 2. This one is placed in the west side where the wind comes. The three-dimensional model recreate the distribution of structures, pavements and vegetation and it is composed by a mesh of 175 x 100 x 25 square cells. Each cell has a dimension of 6(x) x 7(y) x 3.5(z) meters.

The following Table 1 reports the main thermal properties of the material adopted in the ante-operam model. The solar reflectance considered for all surface was measured by an albedometer: The roofs are constituted of bituminous materials and measure an albedo of 0.10; the walls albedo measures are included in a range of values between 0.21–0.85; the asphalt have an albedo measure of about 0.11.

Table 1. Solar and thermal properties ante-operam of material in the urban model.

Urban Models	Thickness, m	Density, kg/m^3	Thermal Capacity, kJ/kgK	Thermal Conductivity, W/mK
Wall	0.40	2571	2.73	1.54
Roof	0.27	3770	2.60	0.96
Asphalt	0.01	1500	6.50	0.50

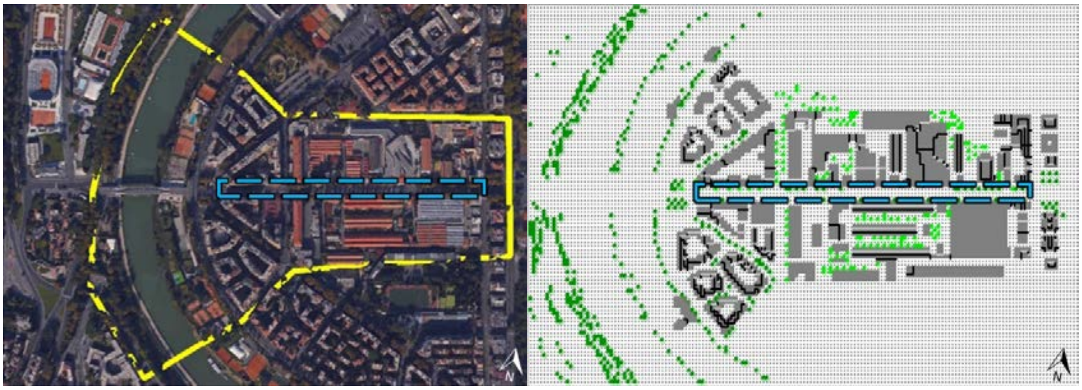

(a) (b)

Fig. 1. Micro-scale models: (a) "Flaminio District" aerial view; (b) ante-operam ENVI-met model.

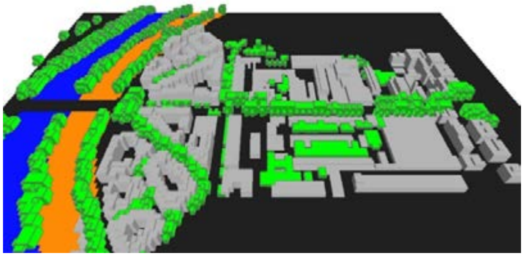


Fig. 2. Three-dimensional computational domain.

4. Microclimatic measurement campaign

The monitoring campaign was carried out with a microclimatic station placed in a point at a height of 1.5 m above the ground level. This point was taken as characteristic of the thermohygrometric conditions of the urban canyon taken into account (blue rectangle Fig. 1(a)).

The station is composed by a LSI Lastem M-Log data logger and a psychrometer for the measure of air temperature and relative humidity. The data of the aforementioned quantities were recorded from 9:00 AM to 4:00 PM during September 17th 2015.

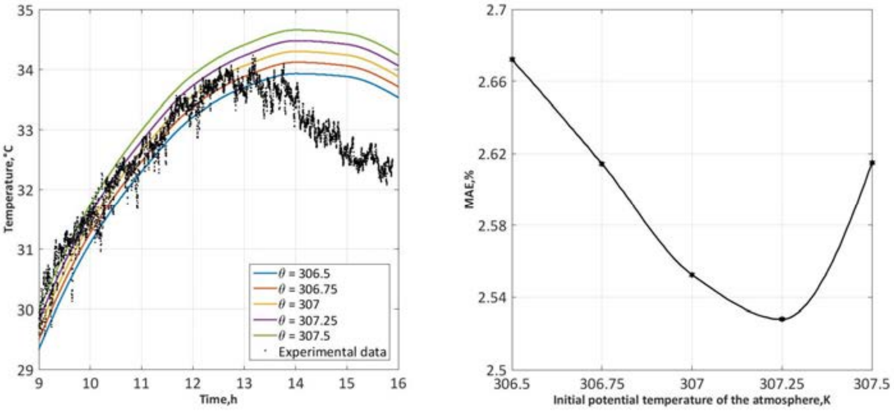
5. Calculation

The numerical analysis reported in this work was carried out with ENVI-met 4.0 [30]. The software is able to simulate and reproduce the micro-climate and the physical behaviour of urban areas. ENVI-met allows to model the interactions between buildings, surfaces, vegetation, air and energy flows of an urban area during a time-dependent simulation. In order to characterize the urban area, the software required several atmospheric quantities able to reproduce the weather conditions of the geographical context taken into account. For the "Flaminio District" model, the parameters used are the following: Wind speed 2.5 m/s, which is the average wind speed in Rome; wind direction 270° (West); specific humidity at 2500 m 7 g water/kg air; relative humidity at 50 %.

5.1. Model validation

The validation of the model was made through the comparison of the experimental measurements with the predicted by the model. In order to reduce the error, it was varied the initial air potential temperature at 2500 m.

Fig. 3(a) shows the trend of the observed and the model-predicted air temperature for few meaningful cases: initial potential air temperature of 306.5 K, 306.75 K, 307 K, 307.25 K and 307.5 K. Different statistical indices [31] were used to analyse the differences between the simulated and experimental data. In Fig. 3(b) where reported the trend of the mean absolute error compared to the experimental data for the cases shown in Fig. 3(a). As shown in the figures, the initial potential air temperature of 307.25 K allows to obtain the minimum mean absolute error of 2.52 %. The other statistical indices for this case have a mean bias error of 0.97 % and a root mean square error of 3.22 %. These values suggest that the model is able to simulate the actual thermal field of the area taken into account.



(a) (b)

Fig. 3. Trend of the observed and the model-predicted air temperature varying the model initial potential temperature of the atmosphere (a) and the corresponding mean absolute error (b).

5.2. Horizontal and vertical air temperature distribution: ENVI-met results

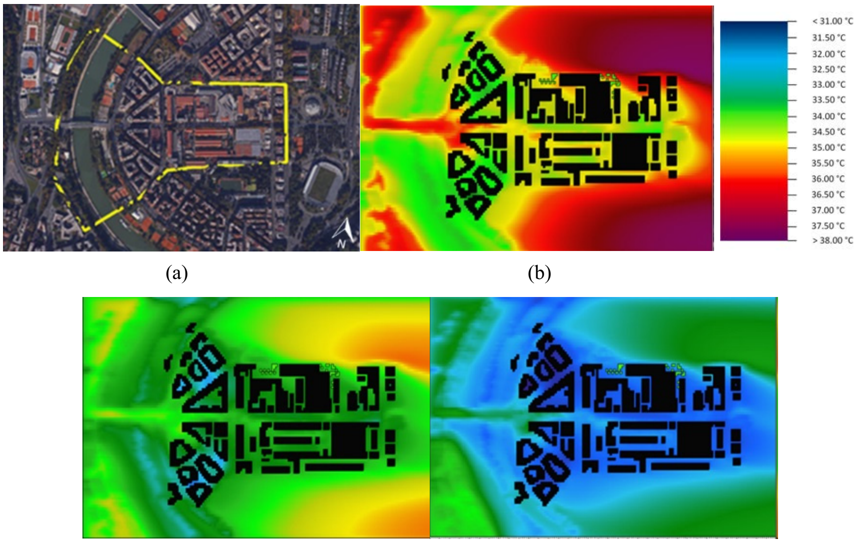
The thermal field results are referred to 2:00 PM and are shown in Fig. 4 and Fig. 5 in which buildings are represented in black while vegetation in green. Fig. 4 highlight the air temperature at a height of 1.75 m above the ground level, while Fig. 5 shows the vertical air temperature field in the centerline of the canyon taken into account (Fig. 1(a)).

The ante-operam thermal condition is shown in Fig. 4(b) in which lower temperatures next to the start of the urban canyon can be noticed because of the presence of the river and the vegetation. As a matter of fact, the wind coming from west allow to transport cool air masses inside the urban area. Outside the area of interest, the temperatures are higher because there is only asphalt without any kind of vegetation and buildings implemented into the model. This is due to reduce the computational time considering only the boundary condition around the analysed canyon shown in Fig. 1(a).

In order to reduce the air temperature in the area taken into account, it was increased the asphalts albedo from 0.11 of ante-operam area, to two different cool pavements with an albedo of 0.40 and 0.65. These are hereinafter referred as post-operam conditions.

Fig. 4(c) and Fig. 4(d) highlight that the adoption of cool pavements leads to an intense decrease of the air temperature. In particular, the adoption of cool materials allow to reduce the air temperature inside the canyon taken into account of about 1 °C with an albedo of 0.40 and 3 °C with an albedo of 0.65. Furthermore, the west canyon entrance, characterized of an high air temperature of about 36 °C in the ante-operam condition, leads to a temperature of 34 °C with an albedo of 0.40 and 33 °C with an albedo of 0.65. This is due to the absence of buildings that can screen the solar radiation and increase the wind speed caused by Venturi effect.

Fig. 5 shows air temperature variation along altitude using different asphalt albedo. It is possible to notice that increasing the altitude the temperature tends to decrease due to the presents of built on the lower layer. Through the use of cool asphalts, the air temperature variation from the bottom and the top of the domain is smaller than in the ante-operam condition.



(a) (b)

(c) (d)

Fig. 4. Air temperature field at an height of 1.75 m from ground level on September 17th at 2:00 PM: (a) view of the “Flaminio District”; (b) ante-operam model with an albedo of 0.11; (c) post-operam model with an albedo of 0.40; (d) post-operam model with an albedo of 0.65.

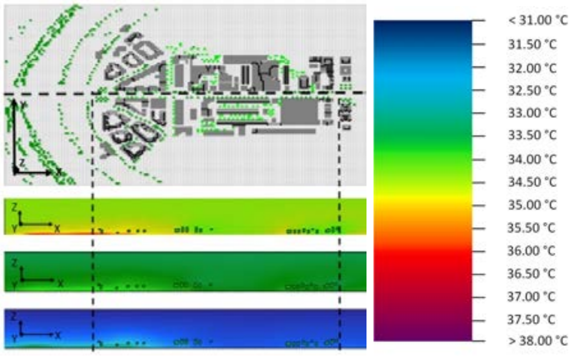


Fig. 5. Air vertical temperature field of the centerline of the canyon taken into account on September 17th at 2:00 PM: (a) ante-operam model with albedo asphalt 0.11; (b) post-operam model with albedo asphalt 0.40; (c) post-operam model with albedo asphalt 0.65.

6. Conclusions

This study analysed the impact of passive techniques for the mitigation of the urban heat island effect in a case study. The objective was pursued through experimental measurements conducted in an area of Rome and with numerical analyses conducted on an environmental and microclimate solver: ENVI-met 4.0. The study area is a part of the "Flaminio District” located in the north of the city, close to the Aurelian Walls, wedged from east by a major road, the Via Flaminia, and from west by the Tiber River. The study area has a surface of 0.218 km^2 and about 3000 inhabitants. On the above described area it has been speculated a redevelopment scenery towards a perspective of using the cool materials. Focusing on the urban canyon situated in the middle of the “Flaminio District”, it was conducted different numerical analysis in order to evaluate the air temperature field varying the asphalts albedo. The simulation results showed a lowering of the maximum outside temperature of 1 °C by increasing the asphalt albedo from 0.11 (ante-operam condition) to 0.40. The decrease in air temperature of the post-operam configuration is up to 3 °C considering an albedo of 0.65 asphalts.

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