EFFECTS OF LOCAL PLANTING ON THE URBAN MICROCLIMATE: A CASE STUDY IN A TOURISTIC CITY IN ITALY

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ABSTRACT
Urban heat island effects are increasingly impacting on the outdoor thermal comfort and human health in urban areas, showing the need for a wiser planning of the urban environment with specific attention to the presence of green areas. Nonetheless, in the past years, several Italian municipalities have removed many trees within urban areas mainly due to the fear of their possible collapse. This paper describes a case study in the coastal city of Senigallia, Italy, aimed at quantitatively assessing the effects of local planting removal on the urban microclimate, in terms of air temperature, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) comfort indexes. The scenarios were modelled using ENVI-met, a holistic three-dimensional modelling software. Simulations were run for the summer period for which a comparison between the domain with and without greenery was carried out. Results show that during summer, the removal of trees significantly modifies the outdoor local microclimate. An average increase in ambient air temperature of approximately 2°C at a height of 1.5 m and in the central hours of a representative summer day was calculated. The comparison between the PMVs and PPDs also shows a substantial worsening of outdoor comfort conditions with an increase of 2 points in PMV values with respect to the case with urban green.
Keywords: ENVI-met, outdoor comfort, urban greenery, temperature.

1 INTRODUCTION

The problem of outdoor comfort is linked to multidisciplinary aspects involving microclimatic and architectural analyses. Comfort is achieved when the usability of a comfortable environment is ensured not only inside confined spaces but also outside buildings, also managing to reduce energy consumption and improving air quality. Besides, the factors involved in reaching a good outdoor and indoor comfort concern both physiological and psychological aspects [1].

The urbanisation and the related change in land use have led to the reduction of urban green spaces increasing the effects of the urban heat island (UHI) phenomenon, i.e., the increase of ambient temperature in urbanised areas compared to neighbouring rural areas. Considering that in Italy coastal municipalities count a population of about 17 million inhabitants, 30% of the Italian population, concentrated on a surface that is about 13% of the national territory, it is essential to study coastal climate and its impact on human well-being [2].

The UHI phenomenon significantly influences global energy consumption and the quality of urban life. Several studies [3]–[5], show that careful urban planning and the choice of the building materials play an important role in determining outdoor comfort.

In the light of the number of elements to consider, the impact that the lack of greenery has on the temperature and on the perception that the population has of the air temperature is often overlooked [6]. In urban environments, several studies [7]–[9], have shown that trees and vegetation in general, help mitigate UHI by increasing the latent heat flux due to evapotranspiration and decreasing the sensible heat flux through shading, all of which leads to a reduction in ambient temperature. On the contrary, it has been demonstrated that the

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absence of vegetation implies a sharp deterioration in the quality of life causing an evident increase in temperature [10]. An interesting aspect is that the amount of urban green appears to be the parameter that most influences the temperature variation and the perceived comfort. Therefore, the layout of the green areas is important but secondary in urban planning [11] and Pastore et al. [5] demonstrated that the effects of shading, radiation interactions and evapotranspiration during very hot days have an even greater impact inside buildings with a decrease in temperature up to 3.4°C. This result confirms the significant consequences also in terms of energy consumption due to increases in cooling demand.

Numerical modelling can represent a powerful tool to support urban planning aimed at developing outdoor climate optimisation strategies. For this study, ENVI-met software was used to simulate the ambient air conditions within a domain including the presence of urban greenery and its absence. ENVI-met® [12] is a multidisciplinary modelling software that allows to model the physical and microclimatic behaviour of buildings, urban greenery, and landscape, including applications for urban planning, climate adaptation, comfort, and human health [13].

This model is a valid tool in the simulation and modelling of outdoor comfort and has been widely used and validated. There is evidence in literature about the ability of the software to obtain excellent performance. Several studies [14], [15], reported that there is a good correlation between simulated and measured ambient air temperatures and, among the others, for the temperature parameters the results obtained were the most accurate.

The purpose of this work is to investigate the impact that the presence of vegetation has on the urban outdoor environment with particular interest in verifying its influence in terms of air temperature variation and alteration of comfort indexes.

In the past, the authors have already carried out simulations based on the evaluation of present scenarios in several locations within the Ancona province to optimise the adoption of UHI mitigation strategies. This paper shows results of a somewhat reverse case study: the renovation of an urban area that included the removal of greenery and, thus, a possible worsening of local UHI effects. The domain is a portion of an urban driveway located in Senigallia, a coastal town in the Marche region of Italy. The area analysed was subject to a conservative and static restoration intervention. The first phase of this intervention included the felling of the tall maritime pines that distinguish the neighbourhood to completely replace them with other species. Even if an accurate assessment had evaluated that they were mostly in good health, this decision was taken due to difficulties in the management of their radical apparatus which had almost shattered the surface of the road and some of the infrastructures located underground.

The temperature and humidity profiles relating to the day chosen for the simulation were collected for a typical summer day and were used to create the boundary conditions using the ‘simple forcing’ method for which, in previous studies, satisfactory results were obtained in the comparison between simulated and measured data [16].

The ‘forced boundary condition’ is the most stable condition because a one-dimensional model is used to stabilise the 3D model. The ‘simple forcing’ method is expressed by applying a forcing to the temperature and humidity variables, attributing to these variables the values of the profiles provided for the chosen period. For this reason, the one-dimensional model shall be well representative of the average conditions of the domain [12].
Finally, chromatic tables were created to analyse the results.

2 URBAN HEAT ISLAND EFFECT

The term ‘urban heat island’ was created to mark a set of phenomena that trigger an increase in ambient air temperature in urbanised areas compared to neighbouring rural areas. It is recorded at all latitudes but at medium and low latitudes, where the climate is warmer, an increase in temperature causes more perceptible and non-negligible effects [17].

UHI presents itself with multiple space–time variations and can be divided into surface UHI and atmospheric UHI. To better approach the study of the phenomena, it is preferable to use different scales both horizontally and vertically. Air UHI involves urban canopy layer, which includes the urban cover layer but below the average height of the buildings, and urban boundary layer which includes the layer above the average height of the buildings. To perform analyses at local level to evaluate the relationship between the development of the urban heat island, the use of certain building materials and the presence of green areas, it is preferable to refer to a model that considers the microscale [18].

The main causes that can lead to the exacerbation of the analysed phenomena are the properties of the materials, the increase in anthropogenic heat, the variation of the wind, the effect of urban canyons, the scarcity of vegetation. The related consequences are many as well, on a general level, the loss of proper thermo-hygrometric conditions has consequences in form of discomfort within population. The increasingly frequent heat waves also have repercussions on the health of the population. Other consequences on the environment of the affected area have been highlighted such as the deterioration of air quality, alterations of the microclimate, variation of the local wind trend [19]. Moreover, the temperature increase in summer causes an increased demand of air conditioning in urban centres, which in turn leads to extra air pollution and an increased anthropogenic heat production: as reported in several studies, every 0.6°C increase in temperature is followed by a 5%–10% increase in energy demand [20].

Finally, there is evidence in literature that, under certain weather patterns, the concentrations of some airborne pollutants increase significantly with the UHI intensity. For example, a study conducted by Lai and Cheng [21] showed that the convergence usually associated with nocturnal UHI causes accumulation of O^3 precursors and other pollutants in significant amounts, worsening the air quality at night and during the following day.

3 MITIGATING EFFECTS OF VEGETATION

The term ‘mitigation techniques’ refers to solutions and strategies aimed at minimising the UHI phenomena and/or the related effects. In such framework, a correct urban planning plays an important role. Throughout such planning, particular attention should be paid to the design and redistribution of green areas, which are indicators of excellent urban-environment quality as well as sustainable urban development, simultaneously fostering economic efficiency, social equity, and environmental integrity [22].

Regarding UHI mitigation, the advantages offered by urban greenery can be traced back to its ability to favour the processes of evapotranspiration which leads to a lowering of the air temperature as the water is vaporised. In few words, evapotranspiration turns a large quantity of sensible heat into latent heat so to lower local ambient air temperature. Trees also provide shading with a consequent reduction in the amount of incident solar radiation absorbed and a consequent reduction in energy consumption for cooling in the summer.

Years ago, the different cooling rate recorded between parks and urban areas was brought to light by the study conducted by Ca et al. [23] in Tama New Town, a city located in the western part of the Tokyo metropolitan area, Japan. The observations have indicated that the vegetation, other than causing a surface temperature of the grass cover 19°C lower than that of an asphalted surface and 15°C lower than that of a concrete surface, also implies air temperature at 1.2 m above the ground more than 2°C lower in the park than in the surrounding commercial and parking areas. Furthermore, the fact that immediately after sunset the temperature of the surface of the ground in the park drops faster than that of the asphalt or concrete surfaces of the city leads to the creation of a ‘cool island’ also called ‘cool oasis’ which allows the reduction of the air temperature in a busy commercial area 1 km downwind by up to 1.5°C. This can bring various advantages, including above all a significant reduction in the energy used for air conditioning (about 4,000 kWh from 1.00 pm to 2.00 pm).

Shashua-Bar et al. [24] investigated the predominant role of trees in attenuating the urban heat island and its dependence on the level of coverage offered by the canopy as well as on the density and geometry of the buildings.

4 SIMULATION DETAILS

The study domain covers a stretch of the avenue Anita Garibaldi in Senigallia, Italy, a municipality of around 44,000 inhabitants (October 2023) that during the summer period tends to triple due to the high seaside tourism, in the province of Ancona in the Marche region located by the Adriatic Sea (Fig. 1).

Figure 1: The case study location with a detail of the section of the avenue analysed.

The analysed area goes from the roundabout in Via Marche to Via La Marca for a total of about 90 m in length and about 84 m in the orthogonal direction (highlighted in yellow in Fig. 1). This section appears to be well representative of the characteristics of the entire avenue.

Numerical simulations were performed with ENVI-met software, a model for the simulation of complex urban environments used in interdisciplinary studies for investigating the influences of urbanisation on urban microclimate and on human health, and to allow climate-appropriate urban planning. The potential of the software and its calculations have been validated and verified in more than 3,000 scientific publications and independent studies [12].

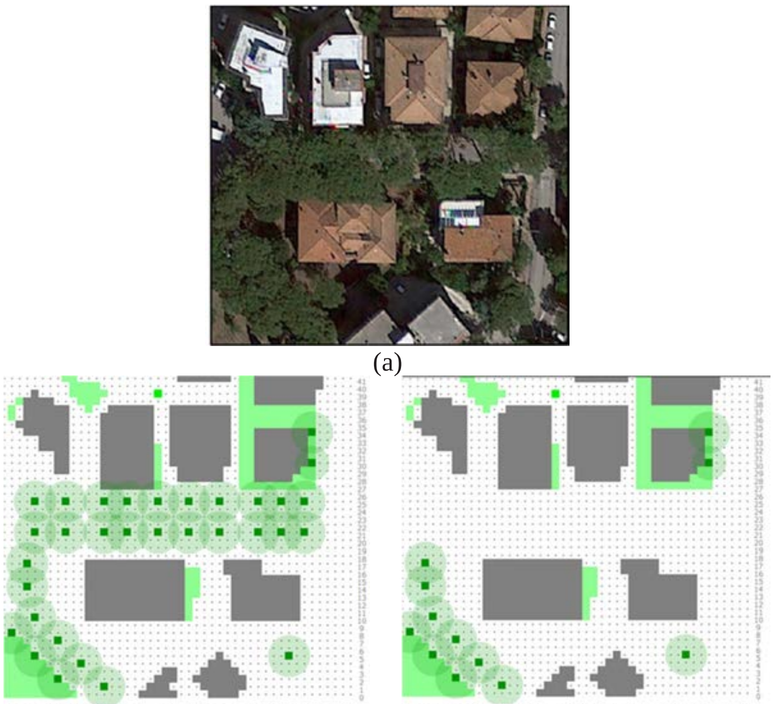
This article reports and discusses simulations carried out to evaluate the trend and evolution of the temperature gradient and the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) comfort indices considering the presence or absence of urban greenery.

The PMV index represents the average judgment of a group of people and gives an idea of how much the real thermal situation perceived by an individual differs from that of well-being. The PMV index can vary from +3 to −3 but ENVI-met considers −4 and +4 as extremes for its calculation. The PPD index indicates the predictable percentage of people dissatisfied with the thermal condition and is mathematically derived from the PMV value.

A comparison has been performed between the air temperature and the comfort indexes, relating to the state-of-the-art situation, i.e., the situation prior to the works with the pine trees still on site, and the situation following the removal intervention, so the same domain but no trees. This comparison was conducted for a representative summer day which was framed, through statistical analysis, on 25 August 2022.

4.1 Simulation characteristics

The domain was initially investigated using Google Earth software (https://www.google.com/intl/it/earth/about/) (Fig. 2(a)), which also allows spatial measurements of areas. Subsequently, detailed site inspections, including precise measurements, were carried out. Following inspections, information related to the 'ante-operam' scenario were collected such as materials and heights of buildings, flooring types and materials, and type and size of vegetation.



(a)

(b)

Figure 2: (a) Domain from Google Earth; (b, left) Domain in ENVI-met avenue with trees; and (b, right) Domain in ENVI-met rehabilitation scenario without trees.

The domain has been generated within the software with the tools to create input areas in the 'Spaces' section. It has been rotated 45° clockwise in accordance with the actual bearing of the roads, thus the model assumes the main geometries perfectly horizontal and vertical, making it easier to represent them using grids. The area was rendered with a grid of 46 × 42 × 30 cells (x–y–z), keeping the cell size 2 m (dx = dy = dx).

The grid nesting feature was used to reduce the chance of numerical problems due to the interference of the borders with the internal model dynamics. Given the limited extension of the domain, the value used for the nesting grid was 2.

Regarding the ante-operam scenario, the input information and data can be split into two categories: determined values and assumed values. The spatial extent of the domain, the heights of the buildings, the positioning and typology of the plants present on the avenue and the weather data are among the actual values entered. The materials chosen for the creation of the built elements of the domain such as walls and roofs of the buildings and the pavements are among the assumed data. These building materials were selected from the set of materials available in the ENVI-met database according to the results of site inspections.

The buildings were represented with default walls and roofs (albedo = 0.5), with an elevation that varies between 11 and 19 m. For the modelling of the vegetation, three different types of plants were introduced:

- Palm tree, small trunk, dense foliage, small (5 m tall).
- Palm tree, large trunk, dense foliage, medium (15 m tall).
- Pinus Pinea, medium (15 m tall).

The paving material of the sidewalk is granite, characterised by an emissivity value of 90% and an albedo of 0.40, the roughness is 0.01 m according to ENVI-met database. The original road was built in asphalt, whose properties in the ENVI-met software are an emissivity of 90%, an albedo value of 0.20, and roughness 0.01 m (Fig. 2(b left)).

The same features were used to create the post-operam scenario where the Pinus Pinea trees on the boulevard have been removed, as shown in Fig. 2(b right).

Weather data for both simulations were obtained from the Marche Region Civil Protection historical database. The reference meteorological station is in Senigallia at the coordinates 13°12' longitude and 43°42' latitude and at an elevation of 6 m [25].

Hourly values of temperature, relative humidity, and wind speed and direction were entered. The start time was 6 am of the two chosen days, the default value suggested by the ENVI-met guide [12]. Both simulations were run over the next 24 hours. The minimum simulation duration, as suggested by the software guidelines, is 6 hours. Several authors considered 1-hour simulation [26]–[28], whereas other authors up to 72 hours [29].

5 RESULTS AND DISCUSSION

The results of the simulations will be displayed showing the behaviour of parameters chosen as representative for the present study, namely the air temperature and the outdoor comfort indexes PMV and PPD.

The results are related to early afternoon (2.00 pm) on the simulated day thus a time when an elevated air temperature is usually perceived and happens to be an interval far enough from simulation start-time.

5.1 Air temperature variations with changes in tree presence

The following images show maps representing the air temperature of the domain analysed for the ‘ante-operam’ case and for the simulated ‘post-operam’ scenario, without trees.

All output images are characterised by a horizontal view from above and refer to 2.00 pm. Output data is related to an elevation that represents the average bust-height of a generic pedestrian (namely z = 1.40 m), thus representing the value mostly perceived by pedestrians.

5.1.1 Scenario with trees

In full summer (Fig. 3), the central zone of the avenue with trees is characterised by rather low temperatures, which go from less than 25°C to 26°C while other areas, near the other roads within the domain analysed reach about 28°C (pink areas). It is therefore clear that the tree-lined area maintains a temperature at least 2°C lower than the areas on the map characterised by the presence of asphalt and little or no presence of trees.

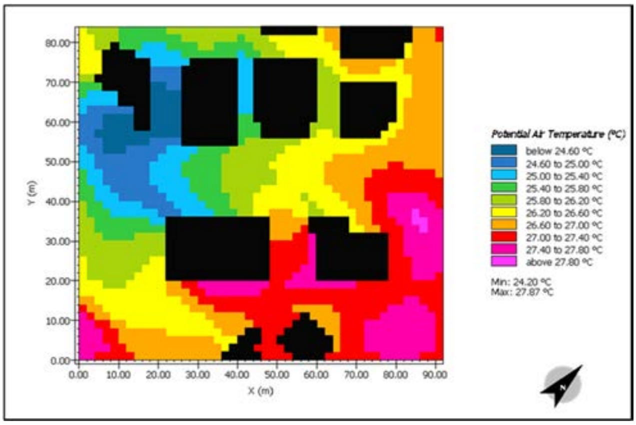


Figure 3: ENVI-met output with trees summer.

5.1.2 Scenario without trees

In Fig. 4 the central area of the domain, devoid of trees, presents colours from red to purple, indicating significantly higher temperatures above 27°C, at least 2°C higher than the situation of the 'ante-operam' scenario (Fig. 3), which showed temperatures around 25°C. The temperatures remain approximately unchanged in the areas with no alteration in tree canopy but also these zones show a small increase. In particular, 'pink' areas expand all over the entire domain.

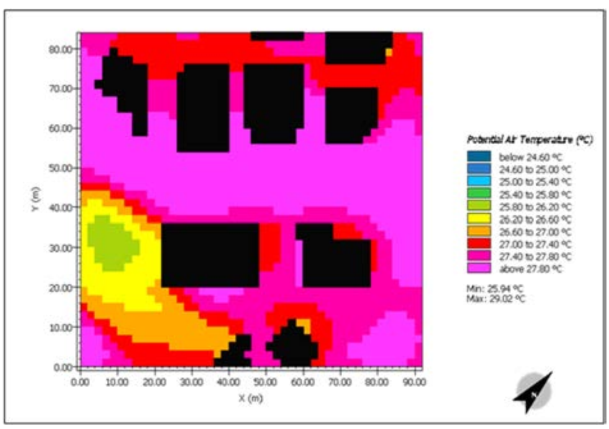


Figure 4: ENVI-met output avenue without trees summer.

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5.2 Outdoor comfort indexes variations with changes in tree presence

ENVI-met can determine, based on meteorological data, PMV and PPD outdoor comfort indices, i.e., indices that attest the thermo-hygrometric human’s well-being, given the set of conditions perceived in the investigated area. Figs 5–8 show the behaviour of PMV and PPD in the various scenarios.

5.2.1 Scenario with trees

Regarding the PMV-index (Fig. 5), the areas affected by the presence of trees show blue colours with PMV values below 1.5, so slightly warm. On the contrary, the areas without trees show colours between orange and red, with PMV values around 3, so perceived as very hot.

Considering the PPD index (Fig. 6), the areas affected by the presence of trees have a percentage of dissatisfied approximately around 16.50% these are the lowest values on the scale.

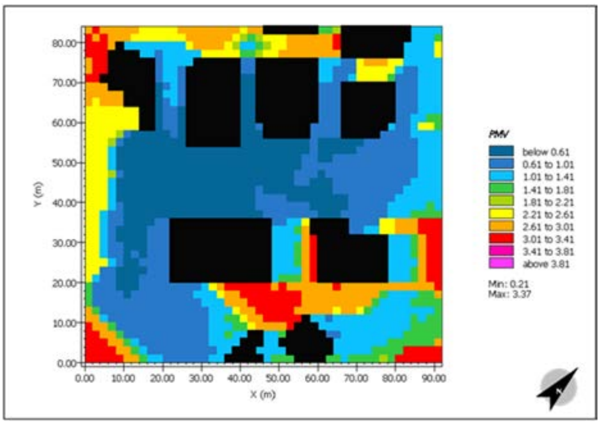

Figure 5: ENVI-met output relating to the scenario with trees for the PMV in summer.

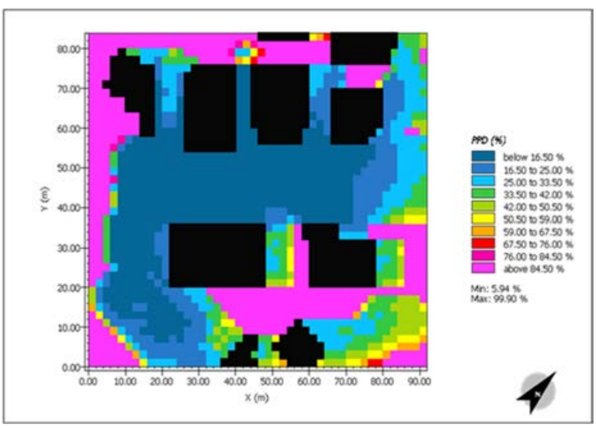

Figure 6: ENVI-met output relating to the scenario with trees for the PPD in summer.

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5.2.2 Scenario without trees

In Fig. 7, regarding the PMV index, the portions of the avenue, now without trees, present in this case a colour scale from pink to red (values of PMV from 3 to almost 4). Therefore, the maximum values recorded are approximately 2 points higher than the state of the art with worse performances.

However, as regards the PPD index (Fig. 8), it is clear from the legend that the portions of the avenue, now without trees, have a percentage of dissatisfied people between 85% and 100%.

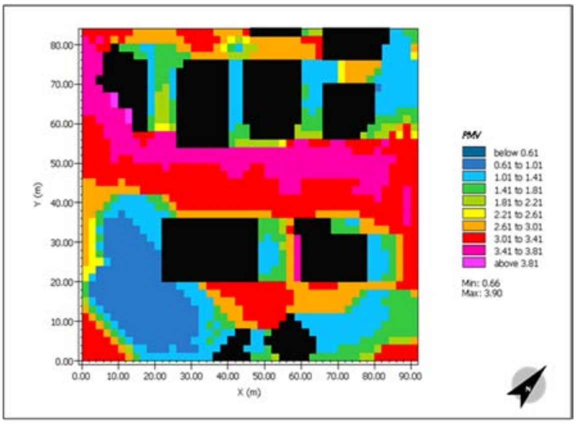

Figure 7: ENVI-met outputs relating to the avenue without trees for the PMV in summer.

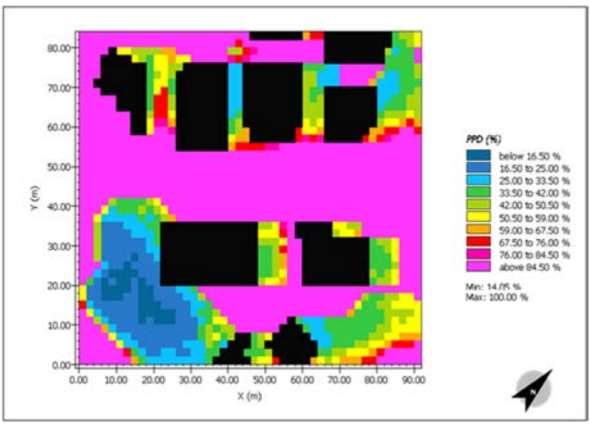

Figure 8: ENVI-met outputs relating to the avenue without trees for the PPD in summer.

6 CONCLUSIONS

The present study described an investigation on the impact that the presence or absence of vegetation in an urban context has on the ambient air temperature and, consequently, on the well-being perceived by the resident population.

ENVI-met software was used and comparisons between tree presence and absence were presented for summer period.

Although the study domain was of limited extension and this software shows some limits such as some approximations in calculations, for meso-research as thermal environment of residential areas, this model performs well.

The results highlighted substantial differences between the two situations examined, mainly in the summer scenarios.

It can be stated that as regards the distribution of the ambient air temperature in the avenue analysed, during summer the removal of trees leads to a significantly increase the local air temperature. The average increase in ambient air temperature is approximately 2°C compared to the state of the art, at a height of 1.5 m and in the central hours of a representative summer day. In the summer case, the comparison between the PMV and PPD indices also shows a substantial worsening of outdoor well-being conditions following the rehabilitation intervention and the tree removal.

This work showed the importance of numerical modelling for assessing potential impacts on outdoor well-being deriving from urban design interventions and, more specifically, it highlighted that maintenance interventions can have a significant and negative impact on the usability of outdoor spaces, confirming the idea that these studies should become mandatory to verify such impacts.

As expected, the present study has demonstrated that the removal of urban greenery has significant negative effects on air temperatures and on the outdoor comfort and that it is important to consider that these affects can be mitigated only in many years through the instalment and the growth of new greenery.

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