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Improvement of the urban microclimate with aromatic and medicinal plants

K. I. Maknea[1], N. Thymakis[2], J. N. Tzortzi[3] and A. C. Asănică[4]

[1]Administrative Region of Central, Thessaloniki, Greece

[2]Center of Agricultural Training, Balkan Botanic Garden of Kroussia, Hellenic Agricultural Organization Dimitra, Thermi, Thessaloniki, Greece

[3]Politecnico Milano, Milano, Italy

[4] University of Agronomic Sciences and Veterinary Medicine of Bucharest, Bucharest, Romania

*Corresponding author kristinamaknea@gmail.com

ABSTRACT

The paper examines the bioclimatic contribution of urban gardening through the use of aromatic and medicinal plants, proposing an innovative approach to urban design. The research aims to evaluate the role of these plants in improving the urban microclimate, focusing on their ability to reduce temperature, increase relative humidity, and contribute to the creation of a synergistic ecosystem that attracts beneficial insects. The methodology involved experimental research at eight sites in Thessaloniki, where temperature, humidity, and solar radiation were recorded. At the sites with aromatic and medicinal plants, a temperature reduction of 10-15% was observed compared to the non-planted areas. Significant improvement was recorded in areas simulating balconies, where potted plants led to a temperature reduction of 5-10%. Furthermore, areas with dense vegetation and water features showed greater humidity, while air circulation was limited, creating adverse thermal comfort conditions. In locations with small arrangements of aromatic plants, a reduction in discomfort perception of up to 26% was observed. The study highlights the innovative potential of integrating aromatic and medicinal plants into urban design for improving the microclimate. Replacing grass in public spaces and using these plants on vertical and horizontal surfaces can improve thermal comfort, aesthetic value, and attract beneficial insects, such as bees.

Keywords*:* aromatic medicinal plants, urban microclimate, urban and bioclimatic design, landscape architecture, urban horticulture

INTRODUCTION

Rapid urbanization and climate change pose significant challenges to modern cities, particularly affecting the quality of the microclimate, thermal comfort, and the well-being of residents. The urban heat island effect and the increase in extreme weather events make it urgent to find sustainable solutions that improve the quality of life for urban populations. In this context, urban gardening, as a form of urban green space, offers an innovative strategy for improving the microclimate and enhancing city sustainability (Ali-Toudert and Thorsson, 2021; Shafique *et al*., 2020). Urban gardening combines aesthetic, environmental, and social benefits through bioclimatic approaches, reducing extreme temperatures, increasing humidity, and enhancing biodiversity (Petrovska, 2012; Hardy and Totelin, 2016).

This paper focuses on aromatic and medicinal plants and explores the impact of urban gardening or urban green spaces on the microclimate and quality of life in modern cities. Their incorporation into urban design offers solutions for improving public spaces and enhancing the energy efficiency of cities (Langemeyer *et al*., 2021). Specifically, it examines the application of bioclimatic principles in landscape architecture, which leverage local climatic conditions to improve thermal comfort and reduce the impact of the urban heat island effect (Li *et al*., 2020; Azunre *et al*., 2019).

Furthermore, the study analyzes the significance of urban gardening for society, the economy, and public health. Citizen participation in gardening projects strengthens the connection with nature, promotes social interaction, and contributes to mental and physical well-being (Piedrahita *et al*., 2020; Schreinemachers *et al*., 2020). The development of therapeutic gardens and the integration of plants into public spaces have already proven effective in enhancing the quality of life for residents, while the creation of green oases in cities highlights the importance of sustainability and resilience (Chew-and Maller, 2023; Tsagalidou, 2013).

This research focuses on harnessing the potential of aromatic and medicinal plants to address urban development challenges, proposing strategies for their integration into urban design and upgrading public spaces. It aims to highlight the multiple benefits of these plants for the urban environment and the health of citizens, offering new perspectives for creating sustainable and thriving cities (Specht *et al*., 2021; Raji *et al*., 2021).

MATERIALS AND METHODS

Study Area

The experiments were conducted in eastern Thessaloniki to minimize external influences such as tall buildings, dense vegetation, or water bodies. The study area included the Research Institute of the Ministry of Agriculture of Northern Greece, the International Hellenic University, and the Urban Horticultural Garden of the School of Agriculture at Aristotle University of Thessaloniki. These locations provided a variety of urban and peri-urban conditions, ensuring comprehensive analysis. Eight experimental sites (Table 1) were selected, representing different surface types, including vegetated and non-vegetated areas, to evaluate the bioclimatic role of aromatic and medicinal plants.

Table 1. Experimental Sites

A	B	C	D	E	F	G	H
Concrete surface with shaded pots of aromatic plants	Soil area with aromatic and medicinal plants	Landscaped 'Mediterranean corner' with plants and natural elements	Bare soil with grass cover	Recreational area with plants, pond, and gravel	Urban garden with mixed vegetation	Concrete surface, no vegetation	Bare soil, no vegetation

Experimental Procedure

The study aimed to evaluate the bioclimatic role of aromatic and medicinal plants in urban environments, particularly their impact on thermal comfort. Eight experimental sites (A–H), representing varying vegetation types and controls, were mapped and characterized. Instruments, including weather stations, soil moisture sensors, and solar radiation

sensors, measured environmental data such as temperature and humidity at ground level to simulate human heat perception. Measurements were conducted on sunny days between 12:30 and 14:00 over a ten-day period (July 4 to August 7, 2023), comparing shaded and non-vegetated areas. Findings were validated using data from the ELGO weather station and Thessaloniki Airport, ensuring robust results representative of broader climatic patterns (Georgi and Zafiriadis, 2006). This framework highlights the potential of these plants to enhance thermal comfort and regulate urban microclimates.
To quantify the microclimatic impacts of vegetation, key parameters such as air temperature and humidity variations, solar radiation reduction, thermal comfort, and standard deviation were analyzed. Temperature and humidity variations were assessed by comparing measurements under shaded and sunlit conditions, highlighting the cooling effect and humidity enhancement provided by vegetation. Solar radiation reduction was evaluated as the percentage of radiation filtered by plant foliage, reflecting vegetation's shading efficiency (del Campo-Hitschfeld et al., 2023). Thermal comfort was measured using the Discomfort Index (DI), which incorporates air temperature and relative humidity to determine heat stress levels. The study compared DI values between vegetated and non-vegetated areas, calculating the reduction in discomfort in shaded environments (Xu et al., 2017; Nurmaya et al., 2022; Georgi and Dimitriou, 2010). The variability of temperature and humidity across different sites was analyzed using standard deviation to investigate the stability of microclimatic conditions. This process will be used to explore the dynamics of vegetated areas compared to non-vegetated surfaces, aiming to assess their respective contributions to microclimatic regulation. Previous studies suggest that vegetated areas are likely to demonstrate environmental variability, while impervious surfaces may exhibit consistent heat accumulation (Bady, 2014; Martinez and Bartholomew, 2017). These methods provide a framework for understanding the bioclimatic role of vegetation in urban environments.
The collected data were tabulated and analyzed using Microsoft Excel. Graphical representations were generated to illustrate comparisons between vegetated and non-vegetated points, enabling conclusions about vegetation's bioclimatic efficiency.

RESULTS AND DISCUSSIONS

The evaluation of environmental conditions (temperature, relative humidity, and brightness) at the eight experimental sites selected to study the impact of the environment on the cultivation of aromatic and medicinal plants reveals apparent differences related to site configuration and climatic conditions on the measurement days. The results are illustrated in graphs. (Figure 1).
At site A, covered with a black mesh for shading and used for potted plant cultivation, temperatures are relatively moderate, with maximum values ranging between 38-40°C on July 24 and 30. The shading effectively reduces temperatures, while humidity remains between 40% and 50%. Brightness levels are moderate due to the shading, with the highest intensity recorded on July 21.
At site B, which features unprotected soil, temperatures reach up to 40°C on July 19 and 23 due to direct solar radiation. Humidity levels are higher compared to other sites, peaking at 60% on July 20 and 24. Brightness is high as the site is fully exposed to the sun, with the most incredible intensity observed on July 21 and 25.
Site C, designed as a Mediterranean garden with various materials, has slightly lower temperatures, primarily due to shading and natural vegetation. Maximum temperatures range from 36-38°C on July 21 and 30, with humidity levels around 50%-55% on July 18 and 22. Brightness is high but mitigated by trees and natural elements in the area.

At site D, which consists of grass-covered ground, temperatures reached 40°C on July 25 and 28 due to intense solar radiation. Humidity remained between 45% and 50%, and brightness was also high as the site was exposed to sunlight without additional protection.
At site E, temperatures are lower, with maximum values around 35°C on July 22 and 25. Due to the presence of water and vegetation, humidity is particularly high, reaching 60% on July 22 and 27. Brightness is high, with peak values recorded on July 21 and 25.
At site F, located in the university's vegetable garden, temperatures are among the highest, reaching 42°C on July 20 and 23. Due to urban conditions, humidity remains low, approximately 30%-35%. Brightness is intense and stable, with peak values on July 21 and 27.
At site G, a concrete area with no vegetation, temperatures peak at 45°C on July 21 and 30 due to the urban heat island effect. Humidity is the lowest among all sites, around 20% to 25%. Brightness is extremely high, as the area is fully exposed to sunlight.
Finally, at site H, which consists of bare soil, temperatures are also very high, reaching 44°C on July 20 and 30. Humidity remains low, around 20% to 25%, while brightness is very high, especially on July 21 and 28.

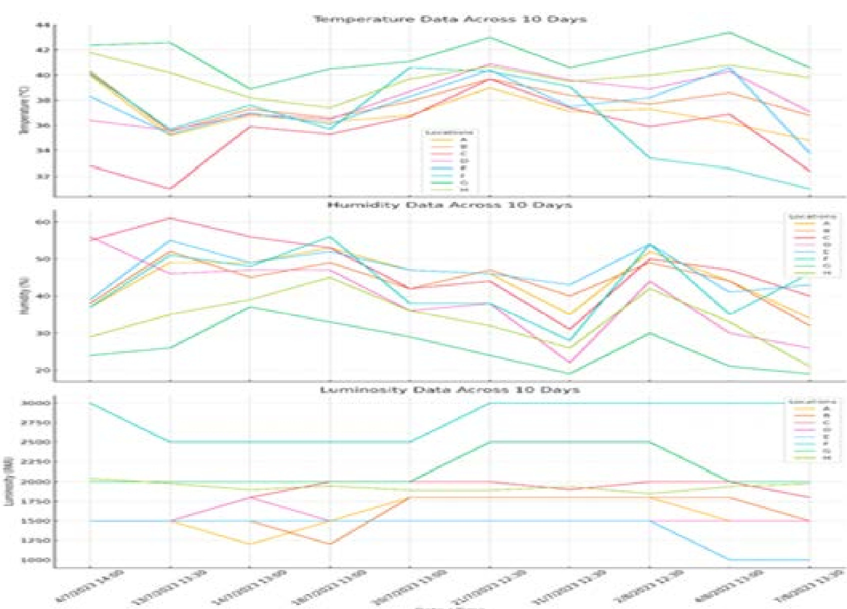

Figure 1. Comparative analysis of temperature, humidity, and brightness in experimental sites

Site D, characterised by a grass-covered surface, served as a reference point for comparing the temperature effects of other surfaces (Figure 2). Vegetated sites (C, E) exhibited consistently favourable variations, ranging from 8.9% to 16.4% relative to site D, confirming the effectiveness of dense vegetation in reducing temperatures. The highest positive variation was recorded at site C on August 2, 2023 (+14.5%), indicating the maximum cooling effect during days with high temperatures.
Sites with limited vegetation or paved surfaces (A, B) showed more minor variations, generally below 5%, and occasionally recorded slightly negative values, suggesting a limited cooling effect. Non-vegetated sites (G and H) demonstrated significant negative variations compared to site D, with values reaching as low as -19.7% (site G, July 13, 2023), highlighting the exacerbation of the urban heat island effect on impervious surfaces.

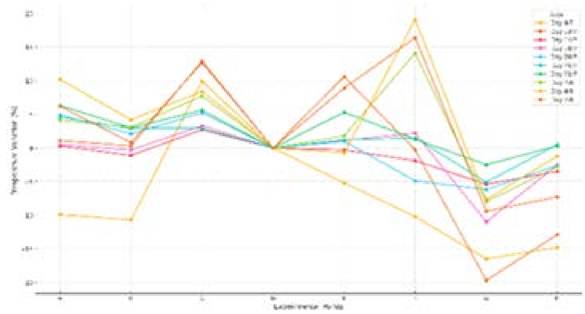

Figure 2. Temperature variation (%) relative to experimental point D across days

Site G, a reference point, is characterized by an impervious surface without vegetation and exhibits the most pronounced urban heat island effect (Figure 3). Vegetated sites (C, E, F) showed significant temperature reductions compared to site G. On August 4, 2023, site F recorded a positive variation of 24.9%, representing the highest cooling effect. Mixed-use sites (A, B) displayed moderate variations between 5% and 10%, with a weaker cooling effect than densely vegetated sites.

Impervious surfaces (H) exhibited negative or nearly negligible variations relative to site G, confirming their lack of contribution to temperature reduction. The smallest variation was recorded on August 7, 2023 (-5.0%).

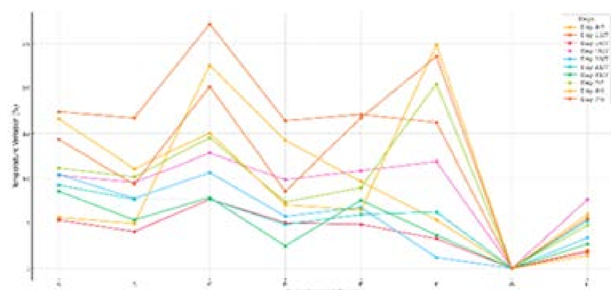

Figure 3. Temperature variation (%) relative to experimental point G across days

Site H, another impervious surface used as a reference point, corroborated the findings observed at site G. Vegetated sites (C, E) showed significant favourable variations, with the highest recorded on July 31, 2023, at site C (+10.3%), emphasizing the effectiveness of dense vegetation in lowering temperatures (Figure 4).

Mixed-use sites (A, B) exhibited moderately favourable variations, ranging between 3% and 6%. Site G consistently showed negative variations, averaging -15.1%, indicating that its impervious surface significantly contributes to increased local temperatures.

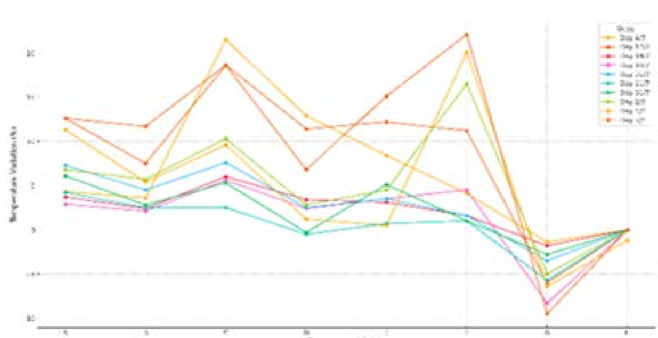

Figure 4. Temperature variation (%) relative to experimental point H across days

Days with higher temperatures (August 2 and 7) highlighted more pronounced differences between vegetated sites and impervious surfaces. For instance, on August 2, 2023, site C demonstrated maximum favourable variations of +14.5% (compared to site G) and +10.3% (compared to site H), underscoring the effectiveness of vegetation in mitigating heat stress conditions.

Figure 5 presents the parameters' average temperature, humidity, and standard deviations for the eight experimental sites studied. Data analysis reveals significant variations in environmental conditions directly associated with site configuration, the presence or absence of vegetation, and surface construction materials.

The calculations showed that the lowest standard deviation (STDEV) values were recorded at site G, covered with concrete (1.4), and site H, covered with soil (1.27). This suggests that surface materials at these test sites are influenced primarily by air conditions rather than other climatic factors. Analyzing the standard deviation (STDEV) and the mean (AVERAGE) provides valuable insights into the impact of urban surfaces on microclimates.

The average temperatures (AVERAGE) indicate that concrete surfaces exhibit the highest values (~41.51°C), demonstrating the pronounced impact of these materials on the urban heat island effect. Temperature standard deviation (STDEV), ranging from 1.27 to 3.47, reflects the variability in temperature across different areas. Higher values (e.g., 3.47) in cultivated areas suggest greater instability, potentially due to varying vegetation density or shading effects.

The average humidity values (AVERAGE), with the highest at 44.60% in shaded areas with potted plants, highlight the cooling effect of vegetation. Conversely, concrete areas exhibit the lowest humidity (~26.20%), illustrating the dehydrating conditions these surfaces create. Humidity standard deviation (STDEV), ranging from 5.53 to 10.75, is highest in cultivated areas (10.75), reflecting the influence of variable factors such as crop type or water management practices.

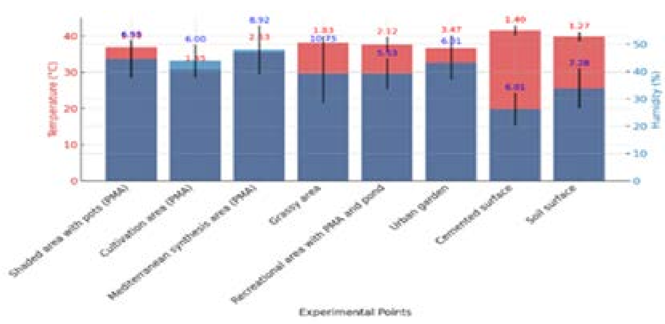

Figure 5. Average temperature and humidity with standard deviation

The graph in Figure 6 illustrates the variability of active solar radiation (%) for each measurement point (A, B, C, D, E, F, G) over 10 days. The analysis focuses on various surfaces, with measurements taken at eight distinct locations (A, B, C, D, E, F, G, H), representing different surface types that may influence the distribution and absorption of solar radiation.

Surfaces A (plants), B (crops), D (grass), and E (park with vegetation and shrubs) display relatively stable solar radiation values, around 24-26%, indicating good capacity for absorption and dispersion of solar energy. In contrast, surfaces G (concrete) and F (urban gardens) exhibit significant fluctuations and lower values, reaching as low as -62.25%. This suggests that these surfaces are more vulnerable to changes in weather conditions and the angle of solar radiation incidence.

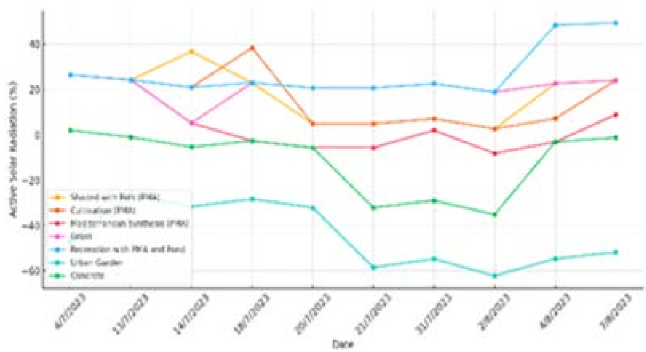

Figure 6. Active solar radiation (%) across different surfaces

Figure 7 illustrates the reduction in the Discomfort Index in shaded areas (DIsh) compared to sunny conditions (DIsun) at site D. The most significant reductions are observed at sites C and E, where values reach up to 9% and 5%, respectively, highlighting the substantial cooling effect of shade. In contrast, sites A and B show less pronounced reductions, with some dates recording negative values. These negative values may be attributed to other environmental factors, such as fluctuations in temperature or humidity, that influence the Discomfort Index.
Additionally, the effectiveness of shade varies over the observation period, suggesting that the impact of shading is strongly dependent on weather conditions and changes in environmental parameters. This variability underscores the complex interplay between vegetation shading and local climatic factors in alleviating discomfort.

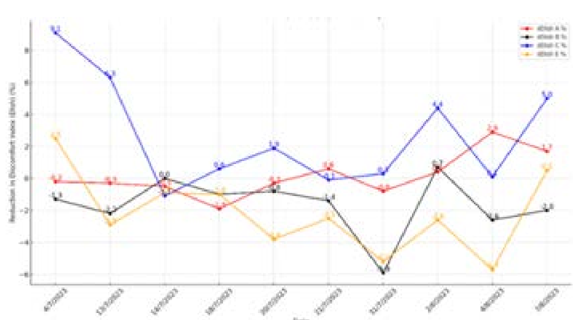

Figure 7. Reduction in Discomfort Index (Dish) (%) across experiment points

CONCLUSIONS

This study highlights the innovative use of aromatic and medicinal plants to improve the urban microclimate, providing significant benefits for environmental quality and urban sustainability.
Temperature and humidity measurements indicate that areas with aromatic medicinal plants, such as site C-100 m^2 landscaped "Mediterranean corner" with succulents, aromatic medicinal plants, stones, slate, tree trunks, *Cupressus sempervirens*, soil, and black geotextile fabric, exhibited the most favourable conditions. In contrast, the concrete site (G-200 m^2 concrete surface with no vegetation (courtyard of the International Hellenic University)) recorded the highest temperatures and the lowest humidity levels. Significant differences were observed in vegetated areas, which enhanced natural cooling and humidity in contrast to sites covered with inorganic materials.

Aromatic and medicinal plants reduce ground-level temperatures and attract beneficial insects, enhancing urban biodiversity.

The findings suggest that incorporating such plants into public spaces and urban surfaces, such as pots or vertical concrete structures, can significantly improve sustainability and environmental aesthetics while reducing maintenance workload and irrigation requirements.

This study underlines the value of aromatic and medicinal plants as tools for urban design to enhance the urban microclimate. It recommends their broader application to develop sustainable and healthy cities. In the future, similar solutions should be implemented in larger urban spaces to enhance environmental quality and create more resilient and functional microclimates.

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