Geographia Technica, Vol. 21, Issue 2, 2026, pp 132 to 149

OPTIMIZING BIOMETEOROLOGICAL COMFORT IN THE CENTRAL PEDESTRIAN AREA OF IAȘI CITY THROUGH VARIOUS URBAN DESIGN SCENARIOS IMPLEMENTED WITH ENVI-MET

Pavel ICHIM [1], ***Robert ȚURCANU*** [1,2] ***& Lucian SFÎCĂ*** [1*]

DOI: 10.21163/GT_2026.213.09

ABSTRACT

The paper analyses the biometeorological comfort of the main pedestrian area from the downtown area of Iași, Romania, during representative weather conditions for summer, aiming to identify sustainable strategies to mitigate or adapt to urban heat discomfort. Historical climate datasets were used to identify the thermal record high of the region, while microclimatic conditions were simulated with ENVI-met software. The work model was developed in ENVI-Met, allowing high-resolution (3×3×3 m grid) simulations of interactions between the lower atmosphere, built surfaces, vegetation, and in-depth soil characteristics. The analysis sampled August 7, 2012 weather conditions, identified as the hottest day between 1961 and 2025, with a recorded air temperature of 41.3°C at the Iași weather station. Three scenarios were simulated, and for each of them the model evaluated potential air temperature (PAT), mean radiant temperature (MRT), and additional biometeorological parameters derived using ENVI-met's BIO-met module, such as skin and clothing temperature with their variations along the selected pedestrian walk. Results show an average air temperature reduction of ~2°C by using cobblestone pavement and up to 20°C lower perceived temperatures, as indicated by MRT, in shaded areas. The complex scenario - represented by a mixture of cool pavement and urban greening - yielded the most significant improvements in thermal comfort, reducing MRT values and mitigating façade heat emissions by up to 9°C through vertical vegetation systems. The findings emphasize the effectiveness of integrated greening and shading strategies in reducing the urban heat island effect. Moreover, they revalidate the capability of ENVI-met-based biometeorological modelling to serve as a decision-support tool for the sustainable design and thermal optimization of urban public spaces.

Keywords: *Urban climate; ENVI-Met; Potential air temperature (PAT); mean radiant temperature (MRT), Iași.*

1. INTRODUCTION

In the context of accelerated urbanization and the intensification of climate change effects, biometeorological comfort in urban pedestrian spaces represents an essential element for ensuring the quality of life in the built environment (Nikoulopoulu et al., 2001). In recent years, numerous studies (Matzarakis et al., 2007, Ng, 2012, Park et al., 2021) have highlighted the role of urban morphology and its components - buildings, surface materials, vegetation - in modifying local microclimatic parameters and, implicitly, influencing the population's thermal perception. At the international level, urban heat island (UHI) effects have been widely documented (Masson et al., 2020), being strongly associated with rapid urban expansion, land-use change, and the increasing dominance of impervious surfaces, all of which contribute to intensified thermal stress in urban environments (Faragallah & Ragheb, 2022).

---

[1] *„Alexandru Ioan Cuza" University of Iași, Faculty of Geography and Geology, Department of Geography, Iași, Romania, pavel.ichim@uaic.ro, lucian.sfica@uaic.ro*

[2] *Department of Climatology, National Meteorological Administration, Bucharest, Romania, turcanu@meteoromania.ro*

[*] *Corresponding author: lucian.sfica@uaic.ro (All authors are equally considered the main author of the article).*

At the European and regional scales, numerous studies have emphasized that urban form and land-use structure play a key role in shaping microclimatic conditions, with compact urban areas generally associated with higher temperatures due to reduced ventilation and increased heat storage (Gusson & Duarte, 2016; Kotharkar & Dongarsane, 2024). Similar findings have been reported in Romanian cities, where urban morphology and the balance between built-up areas and vegetation significantly influence the spatial variability of thermal conditions and the intensity of the UHI effect (Urițescu et al., 2019; Grigoraș & Urițescu, 2024). These results highlight the need for detailed, site-specific analyses of urban microclimates, particularly in rapidly developing urban environments.

The Municipality of Iași, located in the northeastern part of Romania, represents a relevant example for analyzing the interactions between urban structure and the thermal comfort of public spaces. Over the past decades the city has experienced a continuous process of spatial expansion and functional transformation, marked by an increase in built-up surfaces, densification of urban fabric, and changes in land-use patterns (Ursu et al., 2016; Bănică et al., 2017). These processes are widely recognized as major drivers of UHI development, as they reduce evapotranspiration capacity and increase heat storage in urban materials. The city exhibits a well-contoured urban heat island (UHI) both at canopy (Sfîcă et al., 2018) and at the surface (Sfîcă et al., 2023) levels, while recording a high number of days with heat related thermal discomfort (Sfîcă et al, 2017). Simultaneously, the city faces consistent challenges related to the balance between built-up areas and vegetation cover (Foșalău et al., 2024). The central area of the city, corresponding to the Ștefan cel Mare pedestrian boulevard, represents a distinct combination of historical heritage and contemporary urban development, being entirely integrated in the UHI's core. In this area, microclimatic features derived from the UHI manifest intensely during the warm period of the year, influencing the level of thermal comfort for pedestrians and, consequently, the usability of the public space (Sfîcă et al., 2023).

Biometeorological comfort in this type of urban space is conditioned by local factors such as the streets orientation, height of buildings, the type of paving materials with their specific albedo, the presence of vegetation, the wind variability, and the exposure to direct solar radiation (Lau et al., 2015). Within the central area of Iași, these elements interact in a complex way, leading to a high variability of the thermal comfort state depending on synoptic weather conditions and the time of day.

One of the primary applications of ENVI-met consists in evaluating the impact of urban morphology on local temperatures. Numerous research has shown that building density and land-use patterns strongly influence the thermal environment, with compact urban forms exhibiting higher temperatures due to reduced ventilation and increased heat storage in impervious surfaces (Gusson & Duarte, 2016; Urițescu et al., 2019). At the same time, scenario-based simulations have highlighted the important role of green infrastructure in mitigating urban heat stress. Increasing tree canopy coverage, as well as the implementation of green roofs and vegetated façades, has been shown to significantly improve thermal comfort and reduce the UHI effect (Yang et al., 2021; Kotharkar & Dongarsane, 2024).

Surface materials also play a critical role in urban heat regulation. Studies have demonstrated that cool paving materials, such as permeable surfaces and grass grid pavers, can significantly reduce surface and air temperatures, while reflective materials may decrease heat accumulation depending on urban geometry and exposure conditions (Faragallah & Ragheb, 2022; Eingrüber et al., 2024; Sinsel et al., 2022).

In outdoor urban environments, thermal comfort is inherently dynamic, as individuals are exposed to continuously changing microclimatic conditions and rarely reach thermal equilibrium. However, due to the complexity of modelling transient physiological responses and the dependence on individual thermal history, steady-state approaches are commonly applied in urban microclimate studies, offering a practical compromise for thermal comfort assessment (Fischereit & Schlünzen, 2018).

The present work aims to analyze the influence of the urban environment on biometeorological comfort in the Ștefan cel Mare pedestrian area, by evaluating specific microclimatic parameters and advancing some possible solutions to optimize thermal comfort. This topic is relevant also from the citizen perspective, since the renewal of the urban center ignited in the past years a public debate involving also urban climate implications. The study also seeks to identify urban configurations and design solutions that can contribute to reducing biometeorological discomfort and promoting a more sustainable and attractive public space.

2. STUDY AREA

The study area is located in Iași city (**Fig. 1**), northeastern Romania - with its central area located at 47.1° N and 27.5° E - situated within the Moldavian Plateau developed primarily on the lower terraces of the Bahlui River (Minea, 2010; Sfîcă et al., 2023).

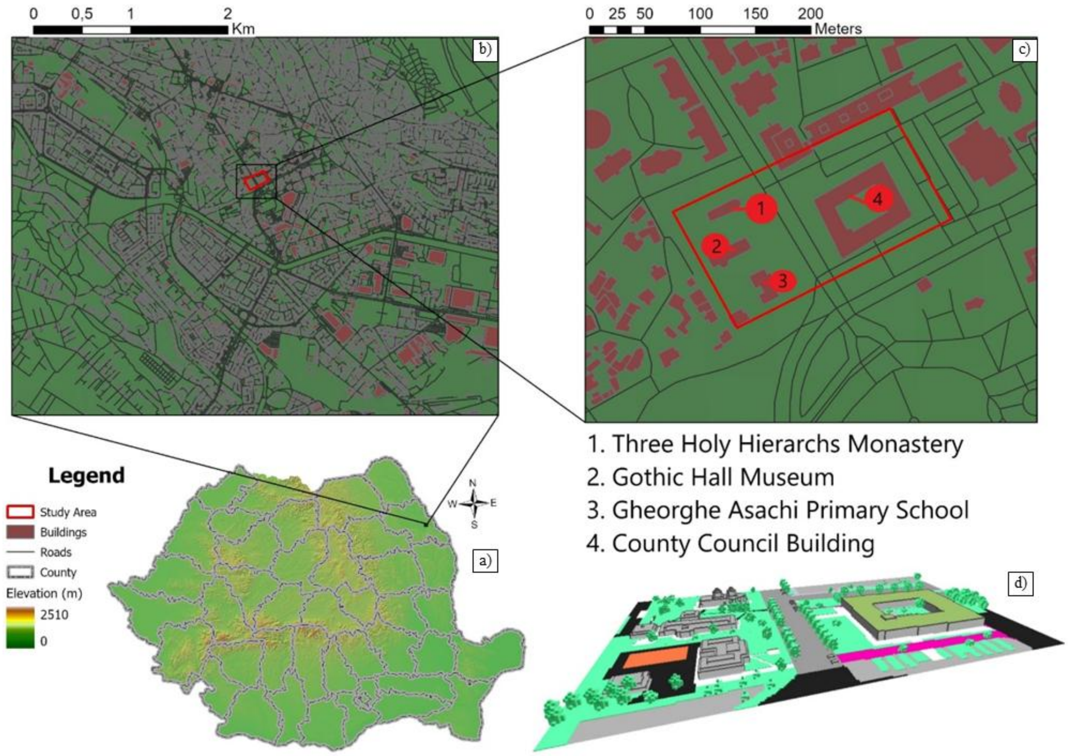


Fig. 1. Location map of the study area in Romania (a), in Iași (b), the selected study area (c) and its built Envi-Met spatial 3D model (d).

Although Iași is classified as Dfb under the Köppen‑Geiger system, recent studies and updated high-resolution climate datasets (Belda et al., 2014; Beck et al., 2018) indicate that parts of Romania, including major urban centers, may exhibit transitional characteristics toward Cfa (Onțel et al., 2025).

Furthermore, the concentration of population, urban expansion, and the high degree of land surface transformation in large cities intensify local thermal conditions, enhancing the urban heat island effect and amplifying warm-season thermal regimes. These processes, combined with regional climate warming trends, support the interpretation of Iași as exhibiting emerging Cfa-like features, particularly in the context of urban climate conditions.

Recent years have recorded significant heat extremes, with 2007, 2012, 2015 and 2019 considered the hottest years especially during summer when heat waves recorded high frequency and duration (Nagavciuc et al., 2022). In this context, in 2012, following a very hot month of July, on August 7, 2012 - when Romania's territory was placed under a strong tropical atmospheric ridge - Iași weather station recorded a maximum temperature of 41.3°C, which represents the highest value observed for the period 1961-2015 (Iordache et al., 2017). It should be underlined that this value also remains the highest recorded up to 2025, based on available observational data. In this context, the simulations presented in the current study can be considered highly relevant for assessing present-day summer thermal discomfort conditions, as well as for indicating potential future extreme heat stress scenarios.

The specific research site covers a 130-meter sector along and nearby the eastern sector of the Ștefan cel Mare pedestrian boulevard, spanning approximately over 30,000 m^2. The perimeter includes the County Council Building (CCB) and two asphalt-paved parking lots to the east, while the southern and northern boundaries are marked by the Gheorghe Asachi Primary School and the Three Holy Hierarchs Monastery, respectively.

3. DATA AND METHODOLOGICAL SETUP

ENVI-met is a three-dimensional non-hydrostatic microclimate model that simulates surface-plat-air interactions at high fluid dynamics, radiation fluxes, thermodynamics, vegetation processes, and soil-atmosphere exchanges (ENVI-Met, 2025). Unlike models focusing on isolated factors like airflow or radiation modeling (OpenFOAM, Radiance, i-Tree Eco), ENVI-met employs a unified approach to simulate holistic environmental changes.

The present analysis focuses on the spatial distribution of Potential Air Temperature (PAT) and Mean Radiant Temperature (MRT), two key variables controlling human thermal perception (Sinsel, 2022). While PAT reflects the thermal state of the air mass independent of pressure variations, MRT represents the combined effect of shortwave and longwave radiation fluxes and is a critical parameter in the assessment of thermal comfort indices indicating the heat load received by the human body. Therefore, MRT is calculated based on the integration of shortwave and longwave radiation fluxes from multiple directions, following the Stefan–Boltzmann law (Sinsel et al., 2022).

In the ENVI-met framework, Potential Air Temperature (PAT) is defined as the air temperature at a reference pressure (model default), and for practical purposes within the 3D model it can be treated as equivalent to the absolute air temperature. Thus, although PAT is formally derived from thermodynamic principles, in near-surface urban simulations it behaves similarly to the standard air temperature (Ta), with only minor differences due to pressure effects (ENVI-Met, 2025).

Mean Radiant Temperature (MRT) represents the integrated effect of all radiative fluxes exchanged between the human body and its surrounding environment and is a key parameter controlling outdoor thermal comfort. It can be expressed as:

$$T_{mrt} = \left(\frac{S_{str}}{\varepsilon_p \cdot \sigma}\right)^{1/4} - 273.15,$$

where S_{str} is the total absorbed radiation flux (including shortwave and longwave components), ε_p is the emissivity of the human body (≈0.97), and σ is the Stefan–Boltzmann constant (Sinsel et al., 2022).

In addition to microclimatic variables, the analysis includes biometeorological outputs related to the human energy balance simulated by ENVI-met (Salata et al., 2016). These include: (1) Tskin (skin temperature), representing the temperature of the body surface in direct interaction with the environment; (2) Tcore (core temperature), referring to the internal body temperature maintained by physiological regulation; (3) Tcl (clothing surface temperature), which describes the thermal state of the clothing layer acting as an interface between the body and the surrounding environment. Furthermore, static Tskin represents the skin temperature under steady-state conditions, assuming constant environmental forcing and no transient physiological adaptation (ENVI-Met, 2025; Sinsel, 2022). Together, these variables provide insight into the physiological response of the human body to outdoor thermal conditions by using dynamic comfort analyses in Bio-met extension of ENVI-met (Salata et al., 2016; ENVI-Met, 2025; Sinsel, 2022).

The model setup was performed using the ENVI-met Headquarters environment, where a dedicated project workspace and database were created to manage site-specific materials, vegetation types, and boundary conditions. The study area was constructed in the Spaces module based on geographic coordinates corresponding to Iași central area (47.16°N, 27.58°E).

The computational domain consists of a grid of 240 × 145 × 32 cells, with a horizontal resolution of 3 × 3 m, ensuring a detailed representation of urban morphology at the pedestrian scale. Such spatial resolutions are commonly applied in ENVI-met simulations to capture fine-scale urban microclimatic processes (Salata et al., 2016; Yang et al., 2021). To improve near-surface accuracy without significantly increasing computational cost, the lowest vertical layers were subdivided into five sub-cells, enhancing the simulation of air–surface interactions, as recommended in ENVI-met modelling practices (ENVI-Met, 2025).

To define the soil types and surface characteristics of the study area, the standardized soil profiles and surface materials provided by the ENVI-met software were used. The default soil type for the entire model domain was sandy-loam. Based on satellite imagery, paved streets were digitized using asphalt road surfaces. Pedestrian areas were represented with granite pavement (single stones), sidewalks with concrete pavement light, colored asphalt areas with asphalt road with red coating, and curbs and selected pedestrian connections with light concrete pavement (**Fig. 2**). This simplification is consistent with the soil characteristics of Iași, where natural soils such as Chernozems and Regosols exhibit predominantly loamy textures, while Fluvisols from the Bahlui floodplain tend toward finer clay-loam textures, while urban Technosols display a high spatial heterogeneity, often corresponding to sandy-loam or loamy compositions due to the mixture of natural and anthropogenic materials (Secu et al., 2015; Secu et al., 2016). In the context of ENVI-met, these conditions justify the use of a dominant sandy-loam soil type, which provides a balanced representation of soil hydraulic and thermal properties, while acknowledging local variability associated with urban land use.

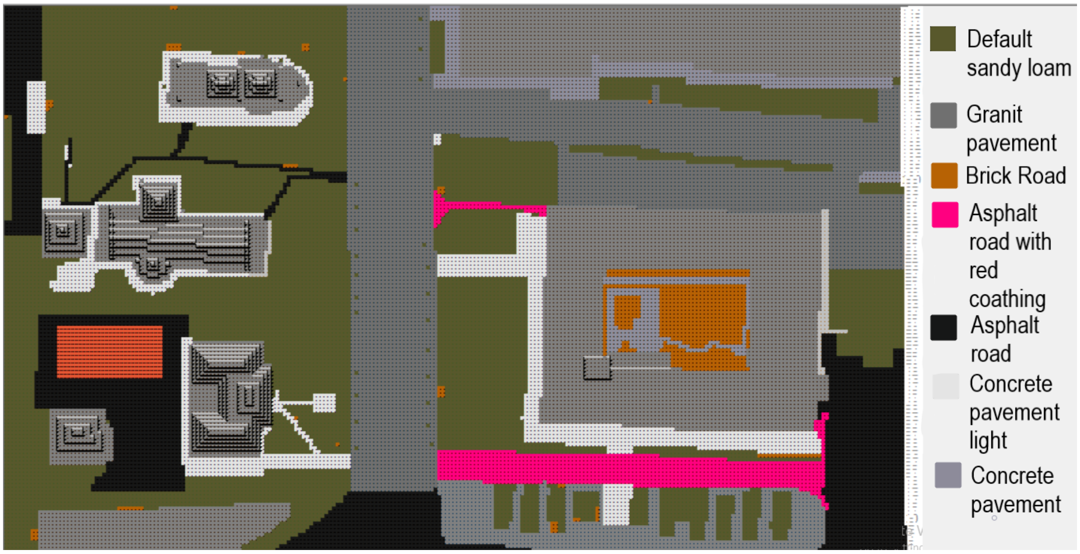
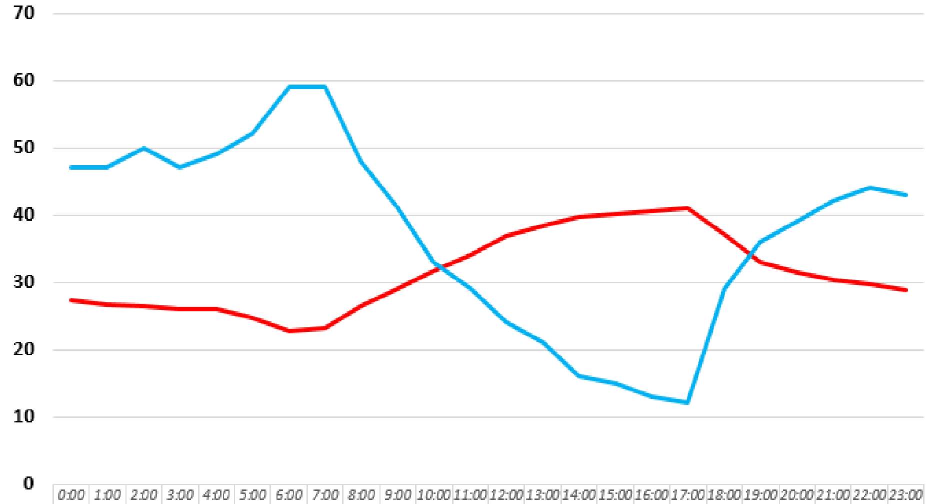


Fig. 2. Surface digitization interface in ENVI-met Spaces for the central area of Iași city.

Building foundations and basement areas were defined using the default cellar soil profile, which represents subsurface conditions beneath buildings and is required for outlining building footprints. Building geometry was then created using ENVI-met's grid-based building system, in which structures are represented by cells with variable heights. Building heights were determined using Google Earth Pro. For example, the CC building has a roof elevation of 73 m and a base elevation of 58 m; by neglecting terrain topography, the building was modeled with an absolute height of 15 m. Buildings with more complex geometries were modeled following the same approach, using three-dimensional building models as references for shape and height. To avoid modeling errors, building footprints were aligned with the previously defined basement profiles. Construction materials were assigned uniformly to all buildings. Due to the lack of detailed information on actual building compositions in the study area, the standard "Default Wall – moderate insulation" material was selected for both walls and roofs.

Vegetation was added using the ENVI-met plant library and was placed exclusively on natural soil profiles to prevent simulation errors. In total, 141 3D plants were included, representing linden (*Tilia cordata*), chestnut (*Aesculus hippocastanum*), black locust (*Robinia pseudoacacia*), thuja (*Thuja occidentalis*), silver fir (*Abies alba*), and Norway spruce (*Picea abies*). The remaining vegetated surfaces were modeled using the standard 25-cm grass surface from the simple plants category.

After completing the model of the study area and saving the model in *.inx* format, we used the ENVI-guide tool to start the simulation process of biometeorological factors. Using climatic gridded daily database from ROCADA (Dumitrescu &Bîrsan, 2015) and National Meteorological Administration of Romania (NMA RO) from SYNOP messages that were issued by official weather stations we identified the hottest day recorded in Iași, corresponding to 07.08.2012, with an absolute maximum temperature of 41.3°C at 17:00 (**Fig. 3**).



	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Air temperature (°C)	27.4	26.7	26.4	26	25.9	24.6	22.8	23.1	26.5	29	31.7	34.1	36.9	38.3	39.8	40.2	40.6	41	37	33	31.4	30.3	29.6	28.8
Relative humidity (%)	47	47	50	47	49	52	59	59	48	41	33	29	24	21	16	15	13	12	29	36	39	42	44	43

Fig. 3. Values used in ENVI-guide for the Simple Forcing process tailored from the weather data recorded on 7 of August 2012

ENVI-guide uses the *.inx* project and a set of climatic data to create a simple forcing *.simx* file used in the subsequent steps. The first data we entered were the date, time, duration of the simulation, and the full and abbreviated names. We also entered the digital reference model (*.inx*) of the study area here. For our simulations, we used the "Multi Core" option, sacrificing the multitasking capacity of the computer used for higher performance and simulation speed (ENVI-MET GMBH, 26.03.2024). We used the "Meteorology" tab to enter climatic data through the "Simple Forcing" function, which requires temperature and humidity values. The entered values are displayed in the central graph. We saved the *.simx* project and entered it into the ENVI-core module for simulation. In ENVI-core, we selected the project database. The program loads all elements, a process that can take several minutes (depending on the spatial and temporal dimensions of the model). Then, we selected the *.simx* file and ran a "check model" module to identify any errors.

To create graphical representations of the results obtained from the simulations, we used "Leonardo" interface in which we imported the *.edx* files obtained after completing the simulation in ENVI-core, selecting the dataset corresponding to the time we wished to represent. To extract the data into a 2D map, we selected the desired parameter from the "Data" menu. For this work, we focused more on factors influencing the thermal comfort and discomfort of pedestrians. Under these conditions, the simulations performed and analyzed are characteristic of a height of 1.5m from the active surface, Leonardo allowing for the extraction of hourly data from points of interest (e.g., modeling on pedestrian routes, surface types, under trees, etc.) (ENVI-MET GMBH, 28.03.2024; ENVI-MET GMBH, 02.04.2024). The methodological workflow is presented in Figure S1 from the attached Supplementary Material.

4. RESULTS AND DISCUSSIONS

4.1. Microclimatic characteristics on current urban environment

To optimize processing time, microclimatic simulations were performed for the 16:00–18:00 local time interval, corresponding to the period of maximum values of air temperature recorded on August 7, 2012.

At 16:00 (**Fig. 4**), the average air temperature in the studied perimeter was 35.7°C, with minimum values of 34.4°C in shaded areas (east of the Three Holy Hierarchs Monastery and north of the Gheorghe Asachi School) and maximums of 37.0°C in the asphalt-paved parking lots north and southeast of the CCB. On the central pedestrian segment, covered with cobblestones, the values were approximately 35°C, indicating thermal variability determined by the differences in material (grass, asphalt and cobblestone) and their exposure to direct solar radiation.

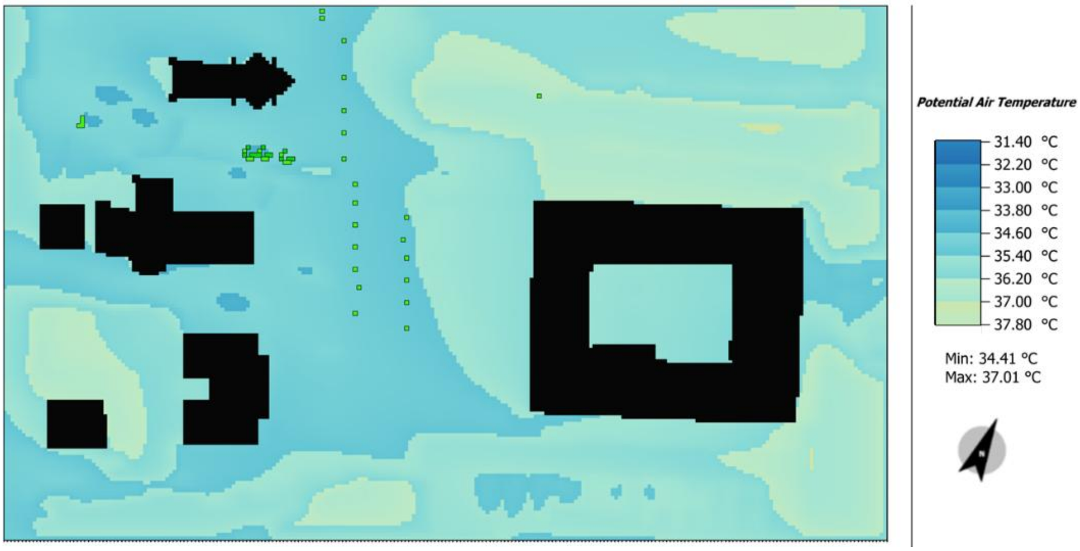


Fig. 4. Spatial distribution of PAT at 16:00 in the current conditions model.

At 18:00 (**Fig. 5**), the mean temperature dropped to 34.4°C, marking a reduction of 1.4°C over the two-hour interval. Maximum values of 35.7°C continued to be recorded on the asphalt surfaces, while shaded areas presented minimums of 33.1°C, as a result of the interplay between vegetation and buildings in moderating local temperatures (Sfîcă et al., 2023; Crețu et al., 2025).

Analyzing PAT values spatial distribution and variation we can observe their underestimation at local level when compared with the values reaching 41.3°C at the official weather station of Iași during the analyzed time interval. This could be explained by a combined result of the small differences between PAT and standard air temperature recorded in sheltered conditions at 2m height, but also of the cold pool island known to develop in very hot summer days in the central area of Iași (Sfîcă et al., 2018). As well, this underestimation indicates that ENVI-MET results could be improved by using local collected data, which is planned in our future work in urban climate modelling.

Fig. 5. Spatial distribution of PAT at 18:00 in the current conditions model.

The MRT presents significant spatial variations depending on local sun exposure. At 16:00 (**Fig. 6**), maximum values of 83.6°C were recorded in areas under the action of both direct solar radiation and heat reflected from the building façades. On the unshaded portions of the pedestrian area, the MRT is approximately 63°C, while in shaded areas, provided by either vegetation or buildings, values of approximately 32°C were obtained.

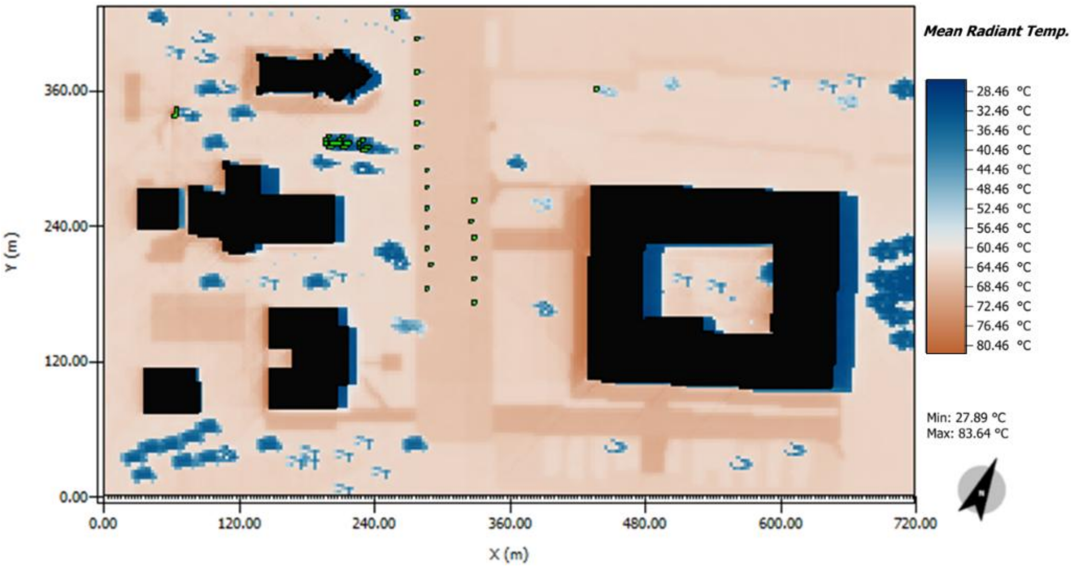


Fig. 6. Spatial distribution of MRT at 16:00 in the current conditions model.

At 18:00 (**Fig. 7**), maximum values decrease to 63.6°C. In the previously identified hotspots, this temperature is now driven by reflected radiation and heat released from building façades, particularly on their northwestern sides. Meanwhile, the pedestrian path averaged 48°C, maintaining a sharp contrast of up to 20°C between exposed and shaded surfaces.

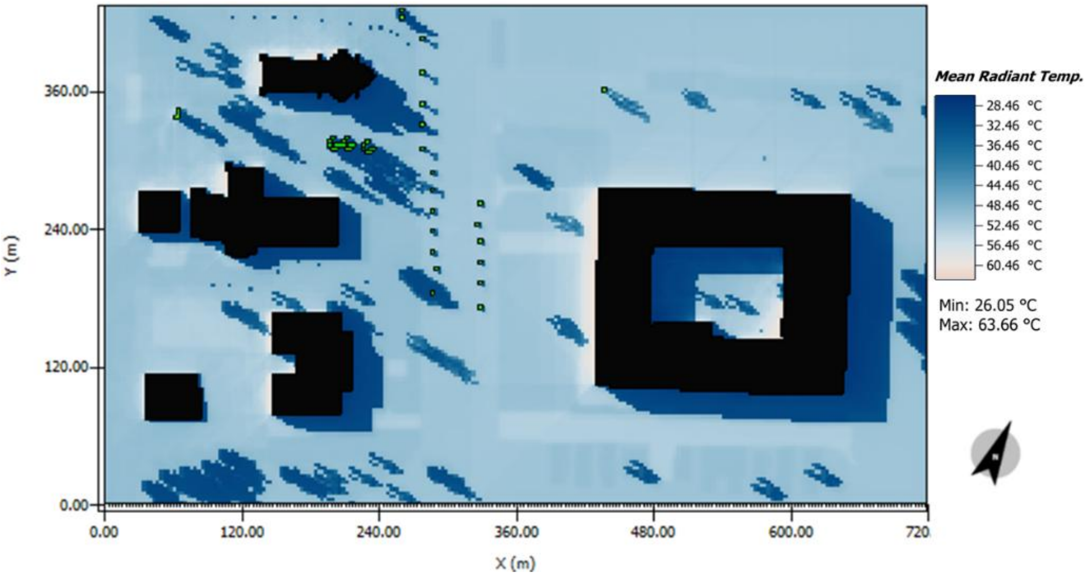


Fig. 7. Spatial distribution of MRT at 18:00 in the current conditions model.

4.2. Modification of the Study Area through Tree Planting and Active Surface Alteration

The analysis of the current situation highlighted significant differences between the thermal behavior of urban surfaces. Shaded areas exhibit temperatures lower by up to 1.3°C, due to the shadow offered by buildings and trees, which reduces the absorption and re-emission of solar radiation (Park et al., 2021). On the contrary, surfaces directly exposed to the sun radiation accumulate heat very fast and retain it for long periods, generating intensified thermal discomfort conditions.

To increase the level of shading, the proposed intervention scenario included planting Horse Chestnut trees (*Aesculus hippocastanum*) with an average height of 17.5m, positioned along the sides of the sidewalks and in the center of the parking lots (**Fig. 8**).

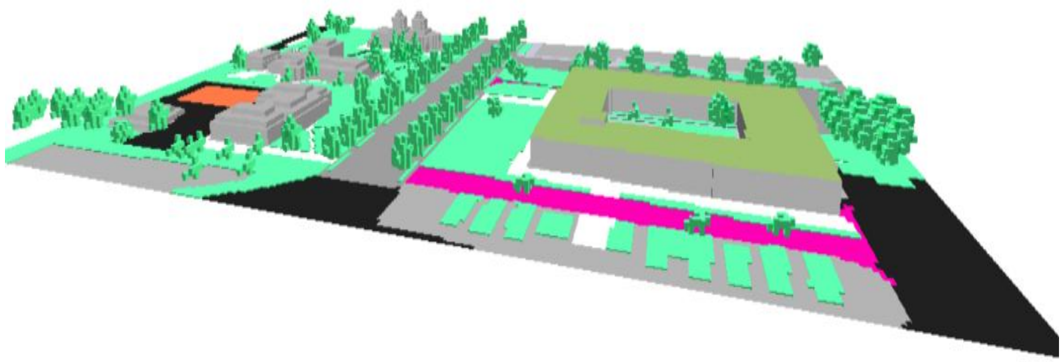


Fig. 8. 3D model of the study area with implemented chestnut trees.

The results obtained highlighted clear thermal differences between the materials used. At 11:00, the surfaces paved with cobblestone recorded an air temperature of 32.7°C, which was 2.3°C lower than that on black asphalt (35°C). The daily maximum temperatures were reached at 16:00, when the cobblestone reached 37.5°C, and the asphalt reached 39.1°C (**Fig. 9a**).

The average difference of~2°C between the two types of surfaces was maintained throughout the analyzed time interval. This supports the nowadays extensive use of cool pavements in urban renewal projects of many cities (Del Serrone et al., 2022), due to their capacity to mitigate the overheating effect during the daytime in maximum sunshine conditions.

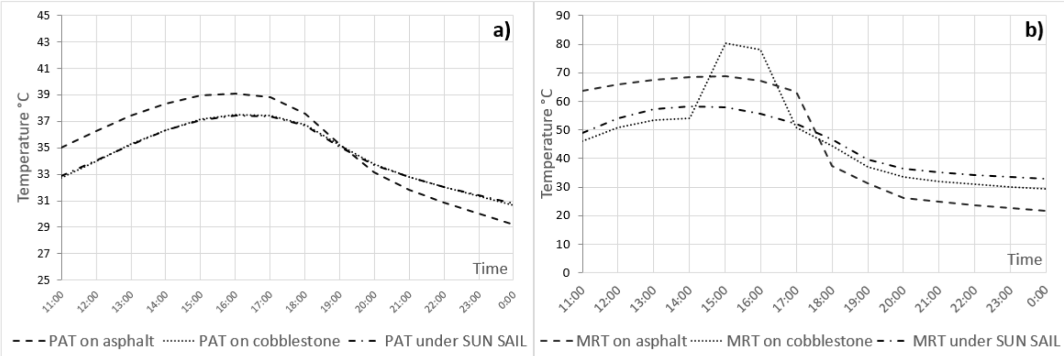


Fig. 9. (a) MRT diurnal evolution on asphalt surfaces, cobblestone pavement and sun sails for the central pedestrian area of Iași city; **(b)** PAT diurnal evolution on asphalt surface, cobblestone pavement and sun sails

The cobblestone exhibited a more favorable thermal response, maintaining felt temperatures (MRT) above 55°C for only 3 hours, compared to 6 hours for the asphalted areas (**Fig. 9b**). Nevertheless, the peak in felt temperature over cobblestone is higher at the time of maximum air temperature (17:00-18:00) and moreover, after 19:00, the MRT on the asphalted surfaces dropped below the PAT, while on the cobblestone the values remained close to it, indicating a slower but stable cooling, which could be also valuable for increasing thermal comfort during wintertime conditions.

Following the implementation of the developed scenario based on trees planting and replacing the asphalted surfaces with cobblestone, the average air temperature over the study region at 16:00 was 35.6°C, which is only 0.1°C lower than in the current situation. The minimum (34.2°C) and maximum (37.0°C) values were also lower than in current conditions, confirming a marginal improvement in thermal comfort (**Fig. 10**). The spatial distribution of temperatures at 16:00 indicates a reduction of approximately 2°C in the areas paved with cobblestone, compared to the original asphalt. Near the trees, the MRT values are 18–20°C lower than in the unshaded areas, confirming the effectiveness of vegetation shading in reducing thermal discomfort (Park et al., 2021).

Fig. 10. Spatial distribution of PAT at 16:00 in the chestnut trees model.

At 18:00 (**Fig. 11**), the average air temperature was 34.2°C, 0.1°C below the values of the initial model. The temperature distribution remains similar, with maximums values (35.4°C) appearing on the exposed surfaces, while minimums (33°C) are concentrated in the proximity of buildings and trees.

Fig. 11. Spatial distribution of PAT at 18:00 in the chestnut trees model

Although trees efficiently reduce direct radiation, the results show that localized shading does not constitute a "one size fits all" solution for reducing thermal discomfort at the pedestrian scale. In shaded segments, the felt temperatures are 18–20°C lower than those of neighboring surfaces, but the effect is limited to areas with consistent vegetation cover and is dependent on the accuracy of input tree data in Envi-Met (Simon et al., 2025), while the type of surface is assessed to be more important than the type of trees (Kaularachichi et al. 2020). However, the magnitude of the average overall differences (0.3°C) suggests that the general impact on the urban microclimate remains low, requiring additional scenarios to extend the shaded areas. As well, for improved accuracy of the results the climate modelling should use data from in-situ observations taking to account the limitations specific to model simulations (Yang et al., 2026). Using the BIOmet module, the thermal behavior of a human subject was compared in the two models: the Original Model (OM) (**Fig. 12**) and the Model with Chestnut Trees (CM) (**Fig. 13**).

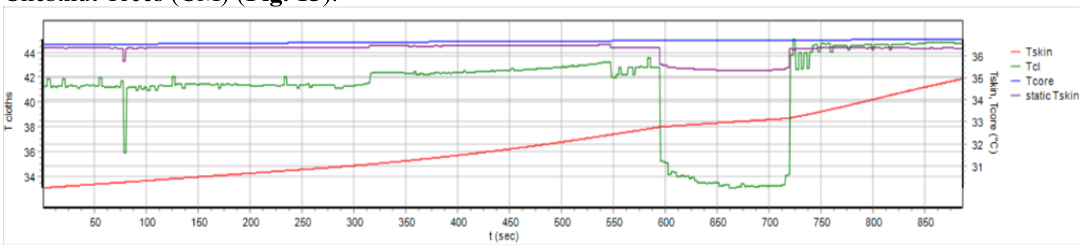


Fig. 12. BIOmet pedestrian route at 16:00 in the original model (OM).

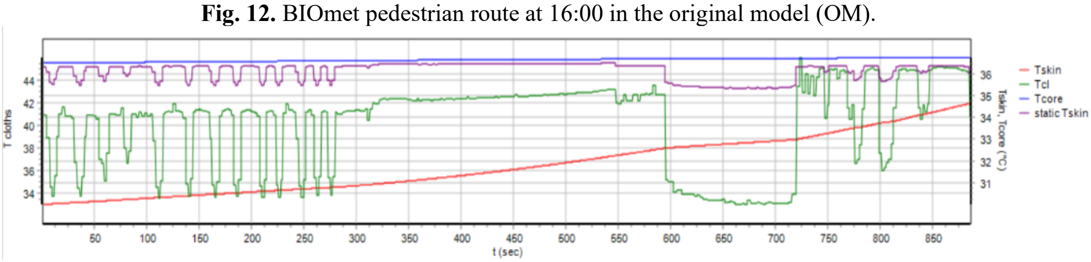


Fig. 13. BIOmet pedestrian route at 16:00 in the chestnut trees model (CM).

The air temperature (PAT) at 16:00 is similar in both cases (35.7°C). The temperature at the clothing level shows differences of 8°C between shaded and exposed areas over distances of 13 meters. In the unmodified segments (the south parking lot and the eastern area of CCB), the values remain identical between the models. The skin temperature is 30°C at the beginning of the route, reaching 35°C in the OM and 34.7°C in the CM after 15 minutes. The average difference of 0.1–0.3°C demonstrates a slight reduction in thermal stress due to the combined effect of shading and surface material modification.

The results confirm that localized interventions involving vegetation and replacing materials with less absorbent ones can generate punctual improvements in thermal comfort. The positive effects are more evident in the proximity of trees and on cobblestone paved surfaces, where the clothing temperature decreases by up to 10°C and the skin temperature is 0.2°C lower at the end of the route compared to the values of the original model.

4.3. Adaptation strategies based on artificial shading and green façades

Building on the results obtained from the tree-planting and surface modification scenario, a supplementary intervention was imagined to further reduce thermal discomfort at the pedestrian level. Although vegetation proved effective in lowering MRT locally, its influence remained spatially limited. To increase the extent and consistency of shaded areas, artificial shading structures of the Sun Sail type were introduced along the main pedestrian path (**Fig. 14**).

The use of sun sail shading systems has been documented in previous studies as an efficient strategy for improving outdoor thermal comfort, particularly in highly exposed urban spaces. Elgheznawy and Eltarabily (2021) demonstrated that covering approximately 60% of a courtyard surface with sun sails leads to significant reduction in thermal stress. In the present study, the economic component was not considered, and the analysis focused exclusively on microclimatic performance. In ENVI-met Spaces, the shading structures were modeled using the Single Wall function to approximate realistic physical behavior. Lateral elements were defined as PVC Sun Sail, providing structural support for a roof composed of photovoltaic panels mounted on aluminium frames (ENVI-MET GmbH, 13.02.2024). This configuration allowed the simulation of both shading and material-related radiative effects.

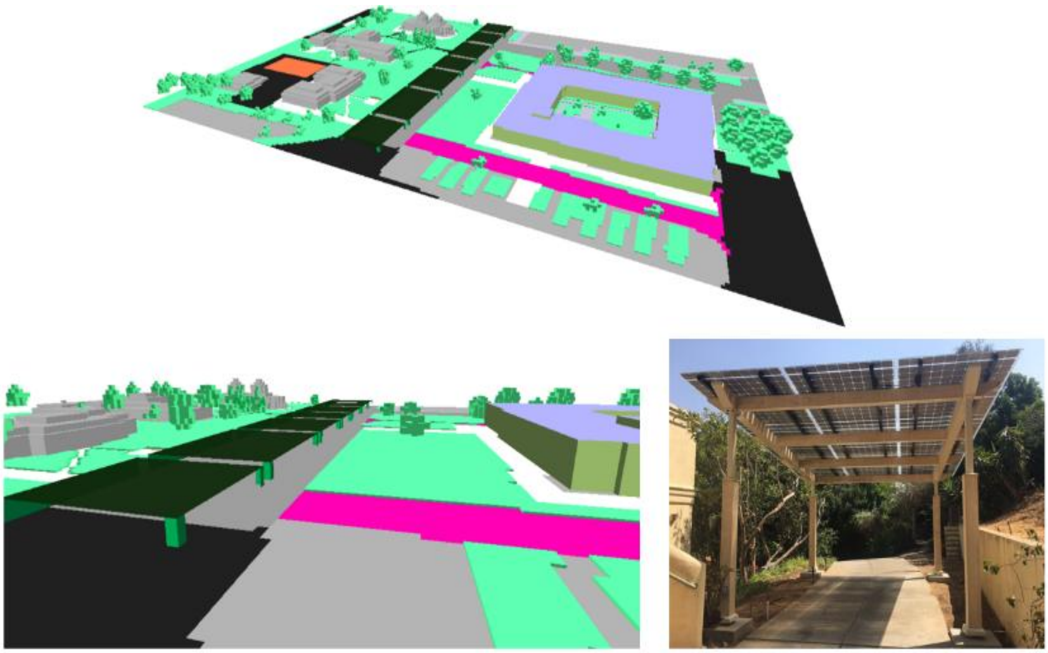


Fig. 14. 3D model of the study area in a scenario with sun sails and green façades.

Simulations at 16:00 revealed that the highest MRT values - reaching up to 68°C - were concentrated near the façades of the CCB. These elevated values are primarily attributed to the accumulation and re-emission of heat from the building envelope. To mitigate this effect, green-vegetated façades were applied to the CCB, as it represents the dominant radiative source influencing the pedestrian zone.

The effectiveness of green façades in reducing wall surface temperatures has been demonstrated by Vox et al (2018), who reported air-temperature reductions of up to 9°C during warm periods and improved insulation performance during colder seasons. In the present model, vegetation was applied exclusively to the CCB, due to its strong impact on adjacent pedestrian areas and the simplicity of modifying façade materials within the Spaces environment (ENVI-MET GmbH, 27.02.2024).

A direct comparison between the shaded model and the unmodified scenario indicates that the maximum PAT at pedestrian height (1.5 m) reached 37.4°C at 16:00, compared to 37.5°C in the original configuration (**Fig. 9a**). Although the difference in air temperature is marginal, the temporal evolution of thermal conditions shows a clear stabilization effect. The rapid temperature increase observed after 14:00 in the original model and the abrupt cooling after 16:00 were significantly buffered, resulting in a more uniform thermal profile throughout the day.

Maximum MRT in the shaded model did not exceed 58.2°C, compared to values of up to 80°C recorded in the original scenario (**Fig. 9b**). During the evening hours (19:00–24:00), perceived temperatures remained approximately 1°C higher than the actual air temperature, indicating residual heat storage within the artificial structures.

From a spatial point of view (**Fig. 15**), maximum values of PAT (36.1°C) were recorded on the asphalt surfaces of the south-eastern parking lot, where perceived temperatures reached approximately 65°C due to direct solar exposure. In contrast, the northern parking area, where asphalt has been replaced with cobblestone, exhibited a potential air temperature of 34.1°C. Excluding localized tree effects (0.2–0.3°C), the observed 2°C difference is attributed to the thermal properties of the paving material. Despite lower air temperatures, perceived temperatures (MRT) in the northern area reached approximately 70°C, reflecting the influence of prolonged solar exposure and radiative exchange. Under the sun sails, MRT were reduced to approximately 54°C, compared to 66°C east of the structures and 70–73°C west of them.

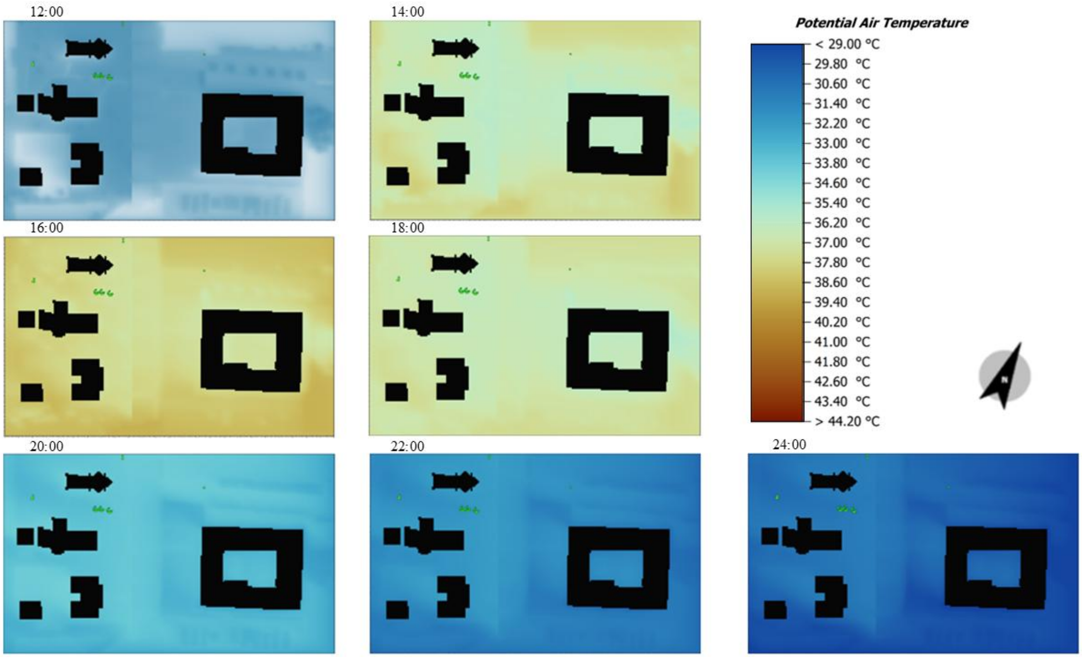


Fig. 15. Spatial distribution of PAT from 12:00 to 00:00 in the model with sun sails.

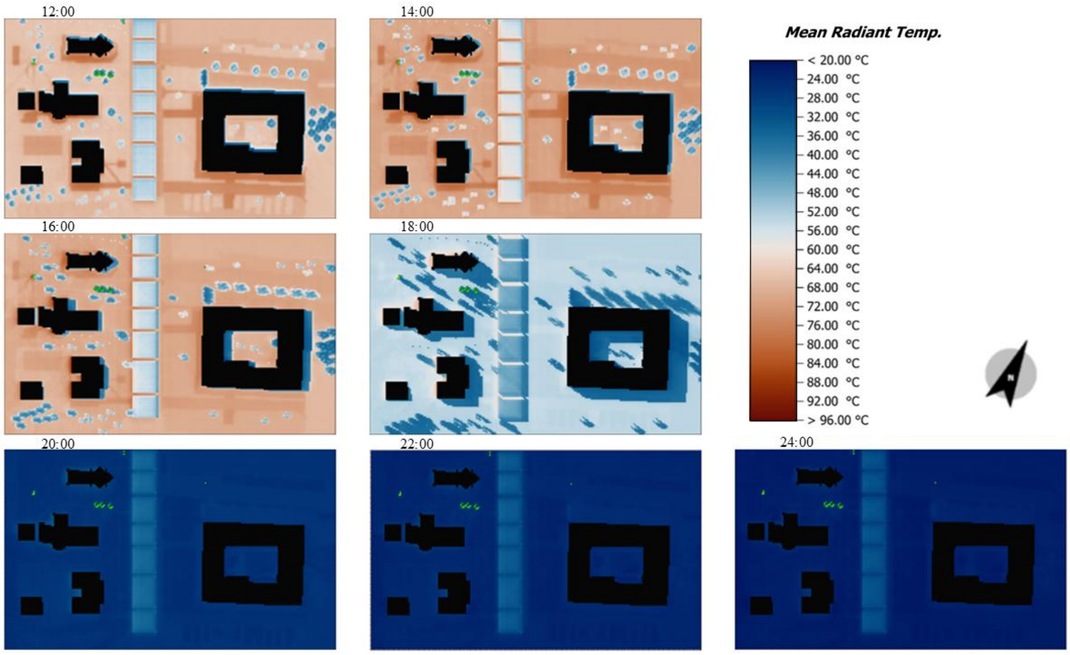


Fig. 16. Spatial distribution of MRT from 12:00 to 00:00 in the model with sun sails.

The highest MRT, up to 76°C, were observed on sidewalks paved with red concrete slabs, confirming the unfavorable thermal behavior of this material (Wardeh et al., 2024). Between 14:00 and 16:00, the average air temperature increased to nearly 38°C, while areas with temperatures below 37°C contracted spatially. Most locations exceeded 70°C in perceived temperature, particularly near west-facing façades. Under the sun sails, air temperature averaged 37°C, increasing to 38.5°C near the southern boundary due to the influence of adjacent asphalt surfaces (**Fig. 16**).

Perceived temperatures beneath the shading structures ranged from approximately 46°C in the eastern sector to 58°C in the western extremities, while minimum values of around 30°C were recorded along the eastern façades of buildings. After 18:00, average air temperatures decreased and spatial variability diminished. The combined influence of buildings and vegetation generated sharply defined shaded zones, where perceived temperatures were up to 15°C lower than in surrounding exposed areas. During the final analyzed interval (20:00–24:00), air temperatures declined uniformly across the study area. At this stage, vegetation no longer exerted a measurable influence on either air temperature or perceived temperature, while shaded areas under sun sails remained approximately 1.5°C warmer than uncovered surfaces due to residual heat emission.

Using the BIOmet module, a direct comparison was performed along an identical pedestrian route starting at 16:00. Skin temperature at the beginning of the route was 30°C in both models. In the original configuration (see Figure 12), it increased to 35°C, whereas in the modified model the increase was slower, reaching a maximum of 34.5°C (**Fig. 17**).

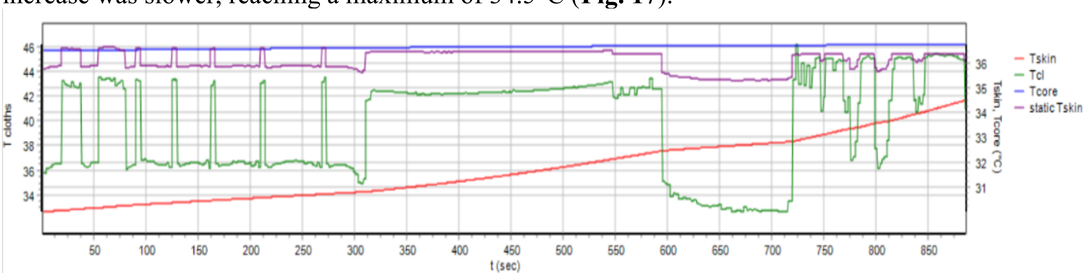


Fig. 17. BIOmet pedestrian route at 16:00 in the model with sun sails.

Clothing-level temperature clearly reflects the influence of artificial shading. When passing beneath sun sails, values decreased from approximately 42°C to 37°C, a pattern consistently observed at each structure. Outside shaded segments, temperature values remained similar to those recorded in the chestnut-only scenario, as the northern CCB parking area was treated identically.

5. CONCLUSIONS

Our analysis proves that ENVI-met has several key advantages when solutions to mitigate or to adapt heat stress are tested, including high-resolution and accurate data, the ability to assess sites without in-situ measurements, and the option to reproduce custom materials, soil profiles, and vegetation.

This study aimed to investigate strategies for enhancing thermal comfort in an urban pedestrian area with a high vulnerability to excessive heat during summer. Initially, vegetation was used to expand shaded surfaces, and paving materials were modified in microclimatically sensitive zones. The results of this approach were mixed. Tree planting had a marginal effect on air temperature, with differences below 0.5°C along the pedestrian area. However, the most notable impact was observed in perceived temperatures during the afternoon due to increased shading. As well, replacing asphalt with cobblestone produced a reduction of approximately 2°C in air temperature. The combined effect of vegetation and improved paving demonstrated promising potential for increasing thermal comfort in the study area.

Following these findings, a more substantial intervention was implemented. Artificial shading structures composed of PVC, aluminium, and photovoltaic panels were installed along the pedestrian corridor, while previously modified areas were retained due to their positive performance. The introduction of these structures resulted in significant improvements: air temperature (PAT) along the pedestrian zone remained below 37°C throughout the day, and perceived temperatures (MRT) under the sun sails were up to 20°C lower than surrounding exposed areas. However, despite of its microclimatic benefits, this method is difficult to be implemented due to its problematic integration in the urban design. As well, a temporary implementation only during summer could be envisaged since during the rest of the year the thermal comfort benefits are null.

Another important conclusion of our work is that ENVI-Met modelling should be based on fine scale weather measurements used both for running the model but also to validate its results.

ACKNOWLEDGEMENT

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS-UEFISCDI, project number PN-IV-P1-PCE-2023-0897, within PNCDI IV.
Data processing and analysis in this paper were supported by the Competitiveness Operational Programme Romania, under project SMIS 124759 - RaaS-IS (Research as a Service Iasi).

REFERENCES

Alexe, C. (2012). *Climate and topoclimate of Iași municipality and metropolitan area (in Romanian)*. PhD Thesis. Iaşi.

Arnfield, A.J. (2023). *Köppen climate classification.* Encyclopedia Britannica, Available from: https://www.britannica.com/science/Koppen-climate-classification [Accessed 4 February 2024].

ASHRAE (2001). *ASHRAE Fundamentals Handbook*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ISBN: 1883413885.

Bănică, A., Roșu, L., Muntele, I., & Grozavu, A. (2017). Towards urban resilience: A multi-criteria analysis of seismic vulnerability in Iasi City (Romania). Sustainability, 9(2), 270. Available from: https://doi.org/10.3390/su9020270.

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data, 5(1), 180214. Available from: https://doi.org/10.1038/sdata.2018.214

Belda, M., Holtanová, E., Halenka, T. & Kalvová, J. (2014). Climate classification revisited: From Köppen to Trewartha. *Climate Research*, 59, 1–13. Available from: doi: 10.3354/cr01204.

Bruse, M. (2023). *ENVI-met 5.5* [Computer software]. ENVI-met GmbH. https://www.envi-met.com

Crețu, ȘC., Sfîcă, L., Ichim, P., Amihăesei, V.A., Breabăn, I.G. & Roșu, L. (2025). Warm season land surface temperature and its relationship with local climate zones in post-socialist cities. *Theoretical and Applied Climatology*, 156, 191. Available from: doi: 10.1007/s00704-025-05409-y.

Del Serrone, G., Peluso, P. & Moretti, L. (2022). Evaluation of microclimate benefits due to cool pavements and green infrastructures on urban heat islands. *Atmosphere*, 13(10), p.1586. Available from: https://doi.org/10.3390/atmos13101586.

Dumitrescu, A. & Birsan, M. V. (2015). ROCADA: a gridded daily climatic dataset over Romania (1961–2013) for nine meteorological variables. *Natural Hazards*, 78, 1045–1063. Available from: doi.pangaea.de/10.1594/PANGAEA.833627.

Eingrüber, N., Berg, P., Korres, W., Löhnert, U., & Schneider, K. (2024). Parameterization and Validation of a High-Resolution Microclimate Model to Identify Temperature Patterns in a Climate Change Adapted Urban High-Density Area. *Available at SSRN 4912045*. Available from: https://doi.org/10.1016/j.cacint.2026.100302.

Elgheznawy, D. & Eltarabily, S. (2021). The impact of sun sail-shading strategy on the thermal comfort in school courtyards. *Building and Environment*, 202, 108046. Available from: https://doi.org/10.1016/j.buildenv.2021.108046.

ENVI-met., (2025). Leading 3D Modelling Software for Urban Cooling and Climate Adaptive Planning. Accessed [2025], https://envi-met.info/doku.php?id=start

Faragallah, R. N., & Ragheb, R. A. (2022). Evaluation of thermal comfort and urban heat island through cool paving materials using ENVI-Met. *Ain Shams Engineering Journal*, *13*(3), 101609. Available from: https://doi.org/10.1016/j.asej.2021.10.004.

Ferrari, A., Kubilay, A., Derome, D. & Carmeliet, J. (2020). The use of permeable and reflective pavements as a potential strategy for urban heat island mitigation. *Urban Climate*, 31, p.100534. Available from: https://doi.org/10.1016/j.uclim.2019.100534.

Fischereit, J., Schlünzen, K.H. (2018). Evaluation of thermal indices for their applicability in obstacle-resolving meteorology models. *Int J Biometeorol* 62, 1887–1900. Available from: https://doi.org/10.1007/s00484-018-1591-6

Foșalău, C.M., Roșu, L., Iațu, C., Dinter, O.V. & Cristodulo, P.M. (2025). Mapping urban changes through the spatio-temporal analysis of vegetation and built-up areas in Iași, Romania. *Sustainability*, *17*(1), p.11. Available from: https://doi.org/10.3390/su17010011.

Grigoraș, G., & Urițescu, B. (2024). Analysis of urban thermal environments using satellite data and urban microclimate modeling. *INCAS Bulletin*, *16*(3), 39-49. DOI: 10.13111/2066-8201.2024.16.3.4

Gusson, C. S., & Duarte, D. H. (2016). Effects of built density and urban morphology on urban microclimate-calibration of the model ENVI-met V4 for the subtropical Sao Paulo, Brazil. Procedia engineering, 169, 2-10. https://doi.org/10.1016/j.proeng.2016.10.001.

Ichim, P. & Sfîcă, L. (2020). The influence of urban climate on bioclimatic conditions in the city of Iași, Romania. *Sustainability*, 12(22), 9652. Available from: https://doi.org/10.3390/su12229652.

Iordache, I., Apostol, L. & Ichim, P. (2017). The land surface temperature distribution during 7th August 2012 using MODIS imagery in Iasi metropolitan area. *Air and Water Components of the Environment Conference*, March 2017, 11–17. Available from: doi: 10.24193/AWC2017_02.

Kaularachichi, T.U.N., Tjoelker, M.G. & Pfautsch, S. (2020). Temperature reduction in urban surface materials through tree shading depends on surface type not tree species. *Forests*, 11(11), p.1141. Available from: https://doi.org/10.3390/f11111141.

Kotharkar, R., & Dongarsane, P. (2024). Investigating outdoor thermal comfort variations across Local Climate Zones in Nagpur, India, using ENVI-met. *Building and Environment*, *249*, 111122. Available from: https://doi.org/10.1016/j.buildenv.2023.111122

Lau, K.K.L., Lindberg, F., Rayner, D. & Thorsson, S. (2015). The effect of urban geometry on mean radiant temperature under future climate change: a study of three European cities. *International Journal of Biometeorology*, *59*(7), pp.799-814. Available from: https://doi.org/10.1007/s00484-014-0898-1.

Nagavciuc, V., Scholz, P. and Ionita, M., (2022). Hotspots for warm and dry summers in Romania. *Natural Hazards and Earth System Sciences*, 22(4), pp.1347-1369.

Nikolopoulou, M., Baker, N. & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy*, 70(3), pp.227-235. Available from: https://doi.org/10.1016/S0038-092X(00)00093-1.

Masson, V., Lemonsu, A., Hidalgo, J., & Voogt, J. (2020). Urban climates and climate change. Annual Review of Environment and Resources, 45(1), 411-444. Available from: https://doi.org/10.1146/annurev-environ-012320-083623

National Meteorological Administration of Romania (NMA RO) data source: www.meteomanz.com who is the ftp server of the National Oceanic and Atmospheric Administration (NOAA). [Accessed: January 2026].

Minea, I. (2010). The evaluation of the water chemistry and quality for the lakes from the south of the Hilly Plain of Jijia (Bahlui drainage basin). *Lakes Reservoirs and Ponds*, 4(2), 131–144.

Ng, E. (2012). Towards planning and practical understanding of the need for meteorological and climatic information in the design of high-density cities: A case-based study of Hong Kong. *International Journal of Climatology*, 32(4), pp.582-598. Available from: https://doi.org/10.1002/joc.2292.

Onțel, I., Amihăesei, V., Micu, D., Dumitrescu, A., & Cheval, S. (2025). Influence of environmental factors on land surface temperature and surface urban heat island. A cross-country analysis in Romania. Sustainable Cities and Society, 128, 106454. Available from: https://doi.org/10.1016/j.scs.2025.106454

Park, Y., Guldmann, J.M. & Liu, D. (2021). Impacts of tree and building shades on the urban heat island: Combining remote sensing, 3D digital city and spatial regression approaches. *Computers, Environment and Urban Systems*, *88*, p.101655. Available from: https://doi.org/10.1016/j.compenvurbsys.2021.101655.

Sandu, I., Mateescu, E. & Vătămanu, V. (2008) *Climate of Romania* (in Romanian), National Meteorological Administration, Academy Publishing House.

Salata, F., Golasi, I., de Lieto Vollaro, R., & de Lieto Vollaro, A. (2016). Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. *Sustainable Cities and Society*, *26*, 318-343. Available from: https://doi.org/10.1016/j.scs.2016.07.005

Sinsel, T. (2022). Advancements and applications of the microclimate model ENVI-met. Dissertation zur Erlangung des Grades "Doktor der Naturwissenschaften" im Promotionsfach Geographie am Fachbereich Chemie, Pharmazie, Geographie und Geowissenschaften der Johannes Gutenberg-Universität Mainz, Available from: http://doi.org/10.25358/openscience-6716

Sinsel, T., Simon, H., Ouyang, W., dos Santos Gusson, C., Shinzato, P., & Bruse, M. (2022). Implementation and evaluation of mean radiant temperature schemes in the microclimate model ENVI-met. *Urban Climate*, *45*, 101279. Available from: https://doi.org/10.1016/j.uclim.2022.101279.

Secu, C. V., Minea, I., & Stoleriu, I. (2015). Geostatistical modeling of water infiltration in urban soils. Carpathian Journal of Earth and Environmental Sciences, 10, 95-104.

Secu, C. V., Juravle, D. T., Paiu, M., Lesenciuc, D. C., Costică, M., Negru, D., & Breabăn, I. G. (2016). Potentially toxic elements in urban soils of Iasi (Romania). Environmental Engineering and Management Journal, 15(3), 687-698. Available from: 10.30638/eemj.2016.074

Sfîcă, L., Croitoru, A.E., Iordache, I. & Ciupertea, A.F. (2017). Synoptic conditions generating heat waves and warm spells in Romania. *Atmosphere*, 8(3), p.50. Available from: https://doi.org/10.3390/atmos8030050.

Sfîcă, L., Ichim, P., Apostol, L. & Ursu, A. (2018). The extent and intensity of the urban heat island in Iași city, Romania. *Theoretical and Applied Climatology*, *134*(3), pp.777-791. Available from: https://doi.org/10.1007/s00704-017-2305-4.

Sfîcă, L., Crețu, C.Ș., Ichim, P., Hrițac, R. & Breabăn, I.G. (2023). Surface urban heat island of Iași city (Romania) and its differences from in situ screen-level air temperature measurements. *Sustainable Cities and Society*, 94, 104568. Available from: https://doi.org/10.1016/j.scs.2023.104568.

Simon, J., Oster, J. & Beck, C. (2025). Exploring the Role of Urban Green Spaces in Microclimate Modeling: Insights from ENVI-met Simulations in Augsburg, Germany, *EGU General Assembly 2025*, Vienna, Austria, 27 Apr–2 May 2025, EGU25-17996. Available from: https://doi.org/10.5194/egusphere-egu25-17996.

Urițescu, B., Grigoraș, G. (2022). The Influence of Building Envelope on the Local Microclimate. 2022 ”Air and Water – Components of the Environment” Conference Proceedings, Cluj-Napoca, Romania, p. 140153, DOI: 10.24193/AWC2022_14.

Ursu, A., Andrei, M., Chelaru, D. A., & Ichim, P. (2016). Built-up area change analysis in Iasi city using GIS. Present Environment and Sustainable Development, (1), 201-216. DOI 10.1515/pesd-2016-00 18

Vox, G., Blanco, I. & Schettini, E. (2018). Green façades to control wall surface temperature in buildings. *Building and Environment*, 129, 154–166. Available from: https://doi.org/10.1016/j.buildenv.2017.12.002.

Wardeh, Y., Rahme, P., Escadeillas, G., Kinab, E. & Ginestet, S. (2024). Cooling potential of cement concrete pavements based on their thermophysical properties. *Case Studies in Construction Materials*, 21, p.e04018. Available from: https://doi.org/10.1016/j.cscm.2024.e04018.

Yang, J., Hu, X., Feng, H., & Marvin, S. (2021). Verifying an ENVI-met simulation of the thermal environment of Yanzhong Square Park in Shanghai. Urban Forestry & Urban Greening, 66, 127384. Available from: https://doi.org/10.1016/j.ufug.2021.127384.

Yang, X., Li, B., Li, N. & Ma, X. (2026). A study of the cooling effect of urban trees: Influencing factors, assessment methods, planning strategies, and impacts. *Theoretical and Applied Climatology*, 157(1), p.31. Available from: https://doi.org/10.1007/s00704-025-05904-2.