

Article

Microclimate Improvement of Inner-City Urban Areas in a Mediterranean Coastal City

Maria Makropoulou

Lab of Urban Morphology, Department of Planning and Regional Development, University of Thessaly, 38334 Volos, Greece; makropoulou@uth.gr or m.makropoulou@gmail.com

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Abstract: This paper investigates urban bioclimatic interventions in the central area of a coastal medium-sized city in Greece. Two urban blocks typical of the urban fabric of the city center and a neighborhood of 38 urban blocks were selected. Different proposed Bioclimatic Renewal Scenarios were investigated through microclimatic simulations using the micro-scale numerical model, ENVI-met. The simulations aimed at assessing various scenarios and examining the effect of the different bioclimatic interventions on the local outdoor environment, such as the application of cool materials, greenery of public open space, and other. Thus a parametric analysis was carried out. A final bioclimatic renewal scenario, based primarily on the parameters, proved to have a positive effect on the local microclimate, was proposed and assessed. The simulation results showed that the final scenario resulted in the most effective heat mitigation strategy for the case studies' microclimate. The vegetation-based scenario also contributed to a significant microclimate improvement in the case studies. The benefits of the various bioclimatic interventions were magnified when these were applied on a spatial scale larger than that of the single urban block, hence on the urban neighborhood scale.

Keywords: urban blocks; bioclimatic interventions; simulations; microclimate

1. Introduction

Contemporary cities, including Greek ones, contain the majority of the world's population and face serious environmental problems. Worldwide, higher temperatures are observed in inner-city areas compared to their suburbs, confirming the presence of the Urban Heat Island (UHI) effect. Similarly, Greek city centers are characterized by particularly high temperatures during summer. Several studies focused on the detection of UHI in the Greek cities, mainly in Athens and Thessaloniki [1–5], as well as in medium-sized cities such as Patras, Herakleion, and Volos [6], and even in smaller cities such as Chania [7], Agrinio [8], and Serres [9].

Especially during summer, the high temperatures in the inner cities areas constitute a particularly significant urban problem due to negatively affecting outdoor thermal comfort, citizens' health, air quality [10], and energy consumption [11–14]. Consequently, the cities' ecological footprint increases [11,15].

On this basis there is a necessity for: (a) the bioclimatic renewal of inner city areas and (b) the adoption of strategies in urban planning aiming to minimize the environmental impact, to upgrade the urban landscape and the residents' quality of life. Towards this direction, several techniques could be adopted in order to improve the local microclimate. Some of them can be easily applied and could also be cost-effective. The most common techniques for microclimate improvement involve:

- *The albedo increase of roofs and paving surfaces* [11,16,17]. The term albedo is defined as the hemispherical and wavelength-integrated reflectance of a material or surface [18,19]. Several studies showed that the albedo increase on a city scale contributes to lowering urban temperatures and thus to decreasing the buildings' cooling demand and the energy consumption respectively [16–23]
- *The use of cool materials at the paving surfaces*, i.e., materials with high solar reflectance and high infrared emittance values [18]. Therefore, cool materials absorb less solar radiation and at the same time release the absorbed heat more easily. As a consequence, these materials develop lower surface temperatures, reducing heat convection from the surfaces to the ambient air, hence leading to lower air temperatures and a cooler environment [16]. Numerous studies focused on the positive influence of cool materials on surface and ambient temperatures [20,23–27]. For instance, Synnefa et al. [23] found that for a maximum solar reflectance difference of 22 between a standard and a cool material, there was a surface temperature difference of 10.2 °C during the summer. Several researchers studied cool materials' application on urban open spaces and their positive effect on the human thermal comfort [11,17,20,28–31]. In all those cited studies, the contribution of cool materials to ambient temperature reduction was confirmed. Santamouris et al. [29] identified a reduction of the peak ambient temperature down to 1.9 °C during a typical summer day. Similarly, Gaitani et al. [11] also estimated an ambient temperature reduction down to 1.6 °C due to the use of cool materials.
- *The use of surfaces with high permeability*, such as vegetated surfaces and pavements made of pervious, porous, or water-retaining materials [14,27]. Asaeda et al. [32] accentuate that the evapotranspiration process at bare soil surfaces constitutes a key parameter in microclimate. The use of permeable materials should be increased in order to allow the exchange of water between the surface and the underlying soil layers, hence fostering the evaporation process [32,33]. As cited in Scholz and Grabowiecki (2007), the basic principle permeable pavement systems is to “collect, treat and infiltrate freely any surface runoff to support groundwater recharge ([34], p. 3831).” Additionally, the permeable pavements decrease the water runoff, enrich and refresh the groundwater, and contribute to pollution prevention and to water conservation due to the recycling process.
- *The increase of vegetation and the use of vegetated systems* (green roofs, green walls, and living walls). The vegetation, particularly trees, contributes to cooling the urban environment in three ways:
 1. Through the evapotranspiration process occurring in plants [19,35–37]
 2. Through shading and solar control. The tree foliage controls the solar radiation incidence on the surface standing below it and absorbs a large part of the solar radiation, while also reflecting a small part of it [36,38]
 3. The albedo of the vegetation is higher (0.18–0.22) than commonly used surface materials such as asphalt (0.05–0.15). Moreover, it is characterized by low heat capacity; therefore, less heat is accumulated in green spaces [19,39]

In addition, vegetation contributes to the improvement of air quality [36,40], controls the air circulation and protects from cold seasonal winds [37], reduces water runoff and improves groundwater quality [36,37], controls noise [41], and reduces building cooling/heating loads (with adequate tree planting, green roofs, etc.) [21,37]. The vegetation could also be applied to buildings' envelope as in the case of 'green' roofs, green 'facades', and 'living' walls. These systems primarily improve energy building performance due to enhancing building insulation and thus reducing the cooling/heating demand. Hence, these applications of vegetation contribute to the improvement of the indoor and outdoor environment [42–46]

- *To provide efficient shading of open space surfaces.* This can be achieved with vegetation (trees) or by using shading devices to control the solar radiation incidence. As cited by Santamouris (2013), “shaded surfaces present a much lower surface temperature as the absorbed direct solar radiation is seriously reduced” [16]

Towards this direction, the current paper presents research into the bioclimatic renewal effect on inner city areas’ microclimate in Greece. The main research objective was to study the impact of similar heat mitigation techniques on the local outdoor environment in the central area of a medium-sized city. Therefore, different bioclimatic renewal scenarios were investigated such as the application of cool materials, greenery of public open spaces, etc.

2. Materials and Methods

2.1. Methodology

The methodological approach of the research objective extends to two basic spatial scales, namely the single urban block and the neighborhood—defined as a cluster of urban blocks. The urban block constitutes the minimal construction unit of the urban fabric, as well as the principal cell composing and organizing the cities. Therefore, the study on a smaller spatial design scale, i.e., the urban block scale, was considered a fundamental prerequisite for the research documentation and preceded the study on the urban neighborhood scale.

The selection of the case study area was based on specific criteria in order to reflect the common problems and features of the urban morphology, the building system and the residential development of contemporary Greek cities. The criteria primarily met two basic components: (a) the common shared urban morphology of central areas in the Greek cities, and (b) the proven need for the areas’ environmental upgrade (Table 1).

Table 1. The selection criteria of the case study area.

Type of Criteria	The Criteria
Spatial and Urban morphology	1. Predominance of the built environment over the unbuilt (urban void and open spaces)
	2. High building density
	3. The existence of a public open space in the study area
	4. Urban blocks (UB), where the building stock was mainly constructed during the first three decades of the post-World War II period
	5. Mix and variety of land uses
Social	6. Social mix (social composition of the population)
Urban Block’s Morphology	7. UB with the common rectangular shape as identified in the urban fabric of Greek city centers
	8. Representative shape of the UB
	9. UB mainly realized with the predominant building system in Greek central areas, i.e., ‘pavilion-courts’ (thus when buildings are constructed in a way that a courtyard is shaped in the interior of the urban block.)
Environmental	10. Degradation of the selected area in terms of air quality (poor air quality)
	11. Degradation of the selected area in terms of traffic congestion and car circulation
	12. Higher temperatures recorded in the selected central area compared to the city suburbs
	13. Lack of green spaces
Other	14. Accessibility in the study area (mainly in the Urban Blocks)

The bioclimatic renewal effect on inner city areas was examined on the basis of multiple scenarios, which referred to the adoption of the abovementioned microclimate improvement techniques. The bioclimatic renewal scenarios of the case study were examined through microclimatic simulations using the micro-scale numerical model, ENVI-met. These simulations aimed at studying the influence of the

different urban renewal scenarios on the local environment (i.e., a parametric analysis). Consequently, this procedure allowed a comprehensive and comparative assessment of the various scenarios since the parameters that had a significant effect on the thermal conditions in the case studies could be identified.

Hence, the introduced research approach is mainly systemized as follows: (a) selection of the case study area based on specific criteria, (b) study on two spatial scales and particularly from the smaller and more detailed one to the larger, i.e., from the urban block to the neighborhood scale, (c) adopting the scenario approach, namely development, examination and configuration of multiple scenarios of bioclimatic renewal, (d) comparative assessment of the various scenarios through microclimate simulations, and (e) analysis of the research results and conclusions.

The ENVI-met software simulated the microclimates' data and estimated the selected thermal comfort index, i.e., the Predicted Mean Vote (PMV) index. Moreover, the spatial distribution of every climatic parameter was fulfilled with ENVI-met. Several studies worldwide have estimated the PMV index with ENVI-met in order to assess the outdoor thermal comfort [47–50]. The calculation of this index was carried out by the ENVI-met Biomet post-processing tool, which uses simulation output data referring to: air temperature T_a , mean radiant temperature T_{mrt} , vapor pressure e , and local wind speed u . Moreover, the required personal settings for the human body were set, namely: the clothing insulation I_{clo} , mechanical energy production of the body M , and mechanical work factor η [51]. The program assumes that the PMV reference person is a 35-year-old male with 75 kg weight and 1.75 m height.

The PMV model “is based on Fanger (1972) comfort model and relates the energy balance of the human body with the human thermal impression using a straight empirical function” [51]. The Fanger model was originally defined for indoor spaces and the initial range of Fanger scale varied between -3 and $+3$. The BioMet 1.0 prognostic model of ENVI-met calculates the PMV index based on the modified Fanger equation by Jendritzky and Nubler (1981) for the outdoor environment. Since the PMV index is a mathematical function of the local climate, in most applications it can exceed the -4 to $+4$ values, although these are off the scale [47,51,52].

2.2. Simulations and Models

The simulations of the parametric study were implemented with the numerical three-dimensional microclimate model, ENVI-met. In this research ENVI-met version 3.1 was used (Table 2). It refers to a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. The model simulates the various surface–plant–air interactions in the urban environment with a typical resolution down to 0.5 m in space and 10 s in time [53–56].

Table 2. The basic simulation assumptions in the ENVI-met model.

Basic Simulation Assumptions in ENVI-Met Model
Flat terrain and simplified box-shaped buildings.
Cubic grid resolution up to 1 m in the horizontal axis. Higher grid resolution can be reached only on the vertical axis.
The wind profile is constant during the simulation.
Building indoor temperature is constant. Buildings have no heat storage.
The 1D soil model is based on the initial temperature and humidity profile of the soil and the various surfaces.
The vegetation model takes into account the humidity and radiation on the soil and in the air. When the A-gs model is used (Jacobs et al., 1996), the photosynthesis rate, the CO ₂ demand, and the state of the stomata are estimated.

The ENVI-met model was chosen because it calculates numerous parameters related to microclimate and to human thermal comfort. The Predicted Mean Vote Index can be estimated by the model, as well as the basic parameters defining the thermal comfort—air temperature, wind speed, relative humidity, and mean radiant temperature. Additionally, it is free-licensed software.

During the last decade, in a wide range of worldwide studies, the numerical model ENVI-met was commonly used for investigating microclimatic conditions in the urban environment [47,48,50,54,57–65]. For instance, several studies have focused on: (1) investigating the

urban canyon microclimate [47,57–59], (2) studying the effect of various parameters on the courtyards' microclimate, such as vegetation, paving materials, water bodies, and urban geometry [47,50,60,61], (3) studying the effect of urban morphology on the local microclimate and the human thermal comfort (calculating indexes as PMV) of various urban spaces [61–64], (4) investigating the microclimate and/or carrying out a parametric study on an urban neighborhood scale [48,54,65–67], and (5) investigating the effect of green parks and vegetation on the local microclimate [49,59,68,69]. Therefore the ENVI-met reliability and accuracy as a microscale simulation model has been repeatedly proven.

In order to implement a simulation, ENVI-met entails detailed input data referring to basic meteorological variables, soil properties, vegetation, paving materials, and building envelope properties. A detailed study on the surface–plant–air interactions inside urban environments with the three-dimensional non-hydrostatic model ENVI-met is presented in Bruse and Fleer (1998) [53].

2.3. Selection of a Typical Day

The city's climate is typical of Mediterranean coastal cities, namely long periods with sunshine throughout the year, relatively hot and dry summers, as well as rainy and mild winters. The warm and dry season usually starts in April and finishes by the end of September [70]. The months of June to August constitute the warmest period in Greece, hence the period when the greatest thermal discomfort can be identified in the Greek urban environment.

Climatic data for the five-year period 2009–2013 (Table 3) were obtained from the city's meteorological station [71] and elaborated to determine the simulation input data for the ENVI-met model. The initial climatic conditions, namely the air temperature, relative humidity, and wind speed and direction, were the same for all simulations. These conditions were defined based on the average daily values of the abovementioned parameters according to the weather station data for the summer periods in 2009–2013. (According to the Hellenic National Meteorological Service, the mean monthly temperature for a certain period is calculated as the average of the mean monthly temperatures of the indicated period [70].) Specifically, the air temperature was set at 27.4 °C, the relative humidity at 60%, the wind speed at 4 m/s, and the wind direction on the northeastern axis.

Table 3. Climate data for the summers of 2009–2013 [71].

Summer Period (June, July, August)	Air Temperature (°C)		Relative Humidity (%)	Wind Speed (m/s)	
	Avg.	Avg. Max.	Avg.	Avg.	Prevalent Direction
2009	26.8	31.7	59.2	3.8	SE, NE
2010	27.9	33.3	59.9	3.9	NE
2011	26.9	31.8	59.9	3.9	ESE, NE
2012	28.5	33.8	57.2	3.5	NE
2013	26.8	31.8	60.6	4.4	NE

Consequently, the typical day selected to run the simulations was the 20th of June 2010. This date satisfies the above climatic conditions, as revealed by the average values of the climatic parameters calculated for the summer months in 2009–2013. This five-year period was chosen because in the summer of 2013 the various microclimatic simulations were implemented.

2.4. Models and Simulation Input Data

The 3D models of the case studies were created in the software with part of their surrounding urban area (Figure 1) so as to accurately simulate the urban environment. The various results and assessment refer to the case study of interest, i.e., for the single urban block. The basic input data are described in Tables 4 and 5. The location, initial climatic conditions, ground conditions, and date and duration of the simulation remained unchanged for all simulations. In all models, extra grid cells were

added at the perimeter of the case study area to ensure that the lateral borders of the model are distant enough from the simulation core area (Figure 1).

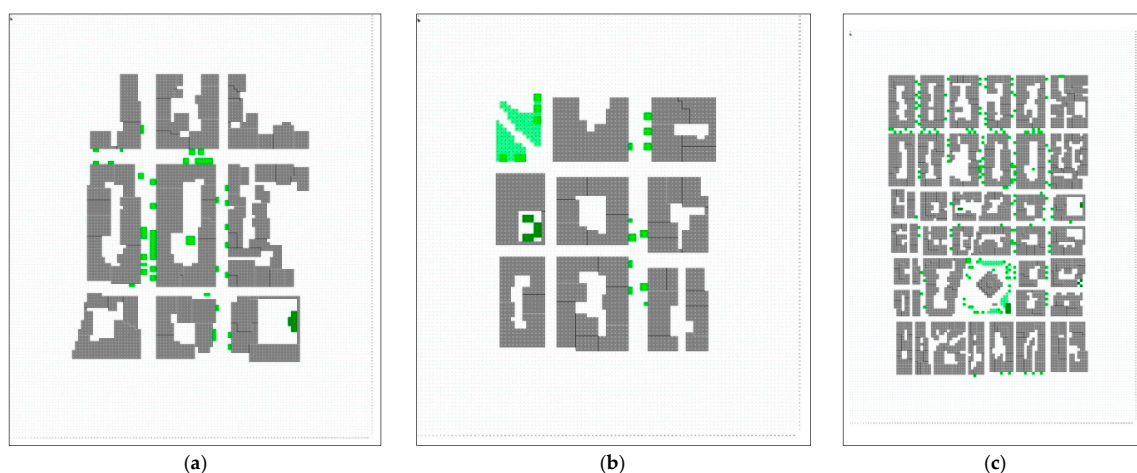


Figure 1. The simulation models of the case studies with their surrounding urban area, as designed in the ENVI-met model, (a) urban block A-UB.A, (b) urban block B-UB.B and (c) urban neighborhood.

Table 4. ENVI-met simulation input data and building properties.

Simulation Input Data			
Simulation Model Size (in meters)		Geographic Location: (Latitude, Longitude)	B39.29°, A22.56°
Urban Block type A (UB.A)	240 × 280 × 59 m	Simulation Date:	20 June 2010
Urban Block type B (UB.B)	200 × 220 × 59 m	Date, Start & Duration of the Simulation:	18:00 (19 June 2010), 30 h
Urban Neighborhood (URBAN)	428 × 588 × 59 m		
Model area (number of grids)		Soil properties in 0.5 m depth	Temperature: 22 °C Relative Humidity: 50%
Urban Block type A (UB.A)	120 × 140 × 30	Soil properties in 1.0 m depth	Temperature: 20 °C Relative Humidity: 50%
Urban Block type B (UB.B)	100 × 110 × 30		
Urban Neighborhood (URBAN)	107 × 147 × 30	Boundary Initial Conditions	27.4 °C
Size of grid cell	2 m, horizontally & vertically	Temperature in 2500 m height:	27.4 °C
Size of grid cell (Urban Neighborhood)	4 m horizontally, 2 m vertically	Wind Speed & direction:	4 m/s, NE
		Relative Humidity (in 2.0 m height):	60%
Building Properties:			
Interior temperature:	25 °C	U-value Walls:	3 W/(m ² ·K)
Albedo Walls:	0.5	U-value Roofs:	2 W/(m ² ·K)
Albedo Roofs:	0.5		

In order to simulate the vegetation processes in ENVI-met, the A-gs model (Jacobs et al., 1996, as cited in [72]) was used. This model calculates the photosynthesis rate, the CO₂ demand, and the state of the stomata. The indoor temperature of buildings was set at 25 °C, which constitutes a typical set point for the air-conditioned indoor environment during the summer. The building properties regarded the heat transmission coefficient and the albedo value of the roofs and walls. The heat transmission coefficient was estimated and set at 3 W/(m²K). This value was set after calculations and refers to buildings with large openings on their facades and little or no insulation. A large part of the city center of Volos was built after the earthquakes of 1954–1956 and before 1979, which was the year when insulation of the building structure became mandatory. The heat transmission coefficient for the roofs was set at 2 W/(m²K). The albedo of roofs and walls was set to 0.5 so as to represent the typical white- and light-colored surfaces of Greek buildings.

Table 5. ENVI-met simulation input data and building properties.

Paving Materials ¹ :	Properties Values		Vegetation ² :	Height (m)	Root Zone	Canopy Diameter Ø
	Albedo	Emittance				
<u>Reference Model</u>			<u>Reference Model</u>			
Conventional asphalt	0.18	0.85	Grass	0.50	0.5 m	–
Conventional asphalt (aged)	0.05	0.85	<i>Ailanthus altissima</i>	15 m	2 m	>5 m
aged concrete tiles and pavement	0.25	0.85	<i>Cedrus deodara</i>	4 m	2 m	<5 m
concrete tiles	0.30	0.90	<i>Cercis siliquasirum</i>	5 m	2 m	>5 m
ceramic tiles	0.40	0.90	<i>Citrus aurantium</i>	5 m, 3 m	2 m	<5 m
white marble	0.65	0.95	<i>Laurus nobilis</i>	4 m	2 m	<5 m
grey marble	0.4	0.95	<i>Ligustrum</i>	6 m, 4 m	2 m	<5 m
soil			<i>Pittosporum tobira</i>	4.5 m, 4 m	2 m	<5 m
Scenarios (+)			<i>Tilia platyphyllos</i>	5 m	2 m	>5 m
Cool light-colored concrete tiles (light yellow grey and green)	0.68	0.94	<i>Aesculus hippocastaneum</i>	10 m	2 m	>5 m
Cool off-white concrete tiles	0.77	0.94	<i>Prunus cerasifera</i>	5 m	2 m	<5 m
Cool beige-yellow asphalt	0.4–0.45	0.93	<i>Morus alba</i>	6 m	2 m	<5 m
Cool off-white asphalt	0.55	0.93				

¹ [73–76] New tree types were created in the model in order to represent local species. The tree parameterization was based on the spatial distribution of the leaf-area density (LAD) using the empirical equation proposed in the analytical approach of LAD calculation by Lalic and Mihalovic [77].

2.5. Reliability and Validation of ENVI-Met

In order to ensure the accuracy of the produced data by the numerous microclimatic simulations, great importance was given to the verification and calibration of the model. The duration of every simulation was set at 30 h, because during the first 6 h of the simulation the model is still being stabilized according to the software programmer [56,78].

The hourly daily values of temperature from the city's meteorological station were compared to the predicted temperature values from the simulations implemented on ENVI-met to calibrate the case study models. This comparison was achieved by building a scatter graph with a linear trend line. This graph mainly shows the correlation between the compared data. Therefore the differentiation or the correlation of the measured and the predicted values can be identified (Figures 2 and 3). The trend line is more precise while the regression coefficient R^2 approaches the unit, thus the data are well correlated.

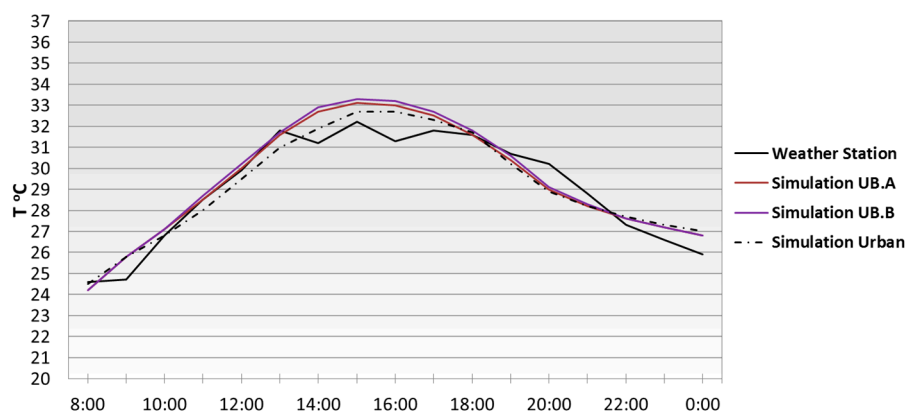


Figure 2. The temperature fluctuation of the weather station measured data and the simulation predicted data for the selected day, the 20th of June 2010.

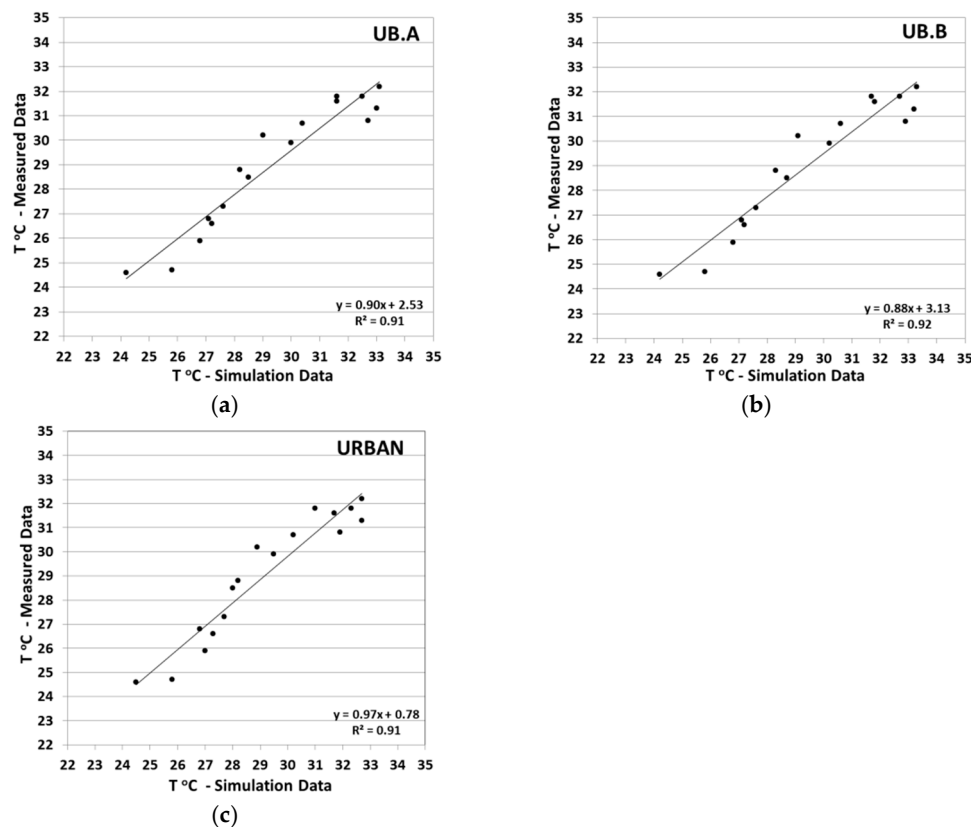


Figure 3. The scatter graphs depict the measured temperature values from the city’s meteorological station and the simulated temperature values on ENVI-met; (a) the urban block type A (UB.A), (b) the urban block type B (UB.B), and (c) the urban neighborhood (URBAN).

The programmer of ENVI-met software claims that deviations ranging from 2 to 4 °C between measured and predicted temperature values may commonly be observed [79]. Rohinton and Fernando [30], in urban areas of Colombo city, Sri Lanka, and in Phoenix, USA, estimated average temperature deviations from 1.06 to 2.83 °C (RMSE). Taleghani et al. [64] compared the measured and predicted temperature values in selected urban blocks in the Netherlands for two selected days. The divergences between the compared data were 0.7 °C and 1.3 °C (RMSE) for each day, respectively. Moreover, the Regression Coefficient R^2 was equal to 0.8. Spangenberg et al. [80], in order to verify the simulation results of the selected urban area in Sao Paulo, Brazil, used a scatter graph to compare them with the field measurement data. The Regression Coefficient R^2 was equal to 0.75. In an urban area in Curitiba, Brazil, Krüger et al. [63] compared the measured and predicted wind speed values with a scatter graph. The regression coefficient, R^2 , was equal to 0.7 for wind speed values less than 2 m/s and 0.8 for values over 2 m/s. Similarly, Ng et al. [68] verified their simulation model for an urban area in Hong Kong and the regression coefficient R^2 was estimated at 0.765 and 0.625.

In the current case studies, the average temperature deviation was estimated between 0.7 and 0.9 °C (RMSE) and thus is considered acceptable, as it constitutes one of the smallest deviations identified in the abovementioned relevant literature. Additionally, the regression coefficient R^2 approaches the unit (0.91 to 0.92) in all case studies, indicating a good correlation of the temperature fluctuation values.

The measured and the predicted temperatures showed an overall satisfying correlation in the case studies. Moreover, between the urban neighborhood model with lower spatial resolution ($dx = dy = 4$ m, $dz = 2$ m) and the other case studies with higher grid resolution ($dx = dy = dz = 2$ m) there was an insignificant differentiation in the data correlation. This confirms the reliability and the accuracy of ENVI-met model once again. Nevertheless, the purpose of this study is to compare the proposed

scenarios and assess the effect of each scenario on the local microclimate. Thus the simulation results by ENVI-met are quite useful and acceptable even with the abovementioned limitations.

2.6. Methodology of the Parametric Study—Bioclimatic Renewal Scenarios

The bioclimatic renewal scenarios studied and the methodology and simulation procedure are schematically depicted in Figure 4.

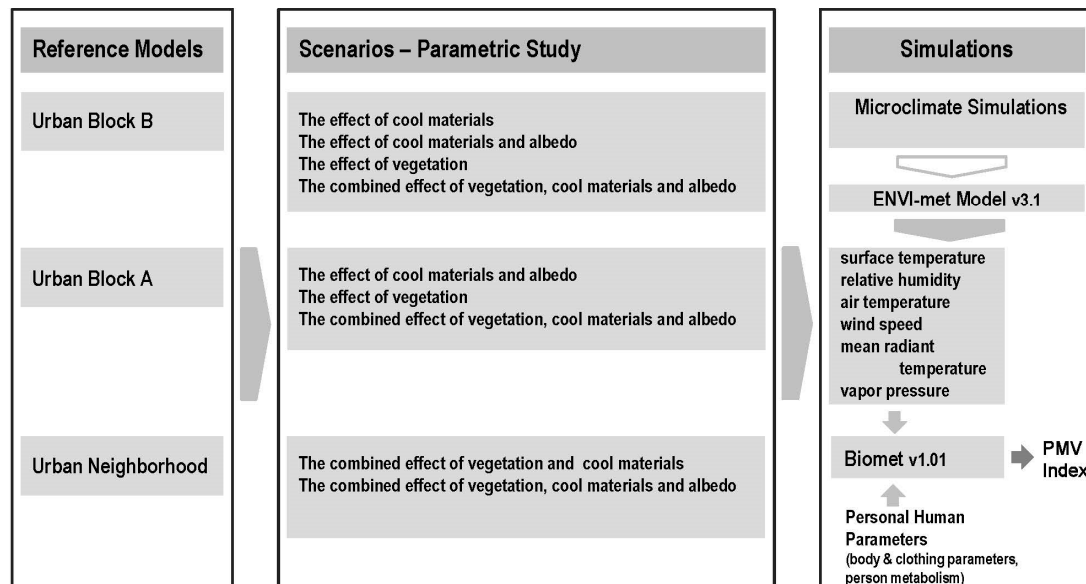


Figure 4. This diagram depicts the methodology of the parametric study, as well as the assessment parameters and the thermal comfort index PMV.

More specifically, these scenarios are described as follows:

1. The 'Cool Materials Scenario' included: the use of cool, light-colored concrete tiles at the paved and impervious surfaces of the urban block (Table 6). These surfaces constitute the urban blocks' enclosed courtyards, sidewalks, pedestrian streets, and roads. The selection of the paving materials satisfied two basic criteria: (a) present high infrared emittance (over 0.9), and (b) ensure the highest possible reflectivity, taking into consideration that the material reflectivity may gradually decrease to 0.5 due to aging [29], as well as cause glare problems or high contrast levels due to being excessively high, namely higher than 0.85 [29]. The surfaces exposed to sunlight for a longer period of the day were paved with high albedo tiles (0.77). The one-way roads were paved with cool, off-white asphalt (albedo 0.55) and the double-direction roads with light-colored asphalt (albedo up to 0.45) in order to avoid optical discomfort from high reflectivity while driving.
2. The 'Cool Materials & Albedo increase of the Building Envelope' Scenario included: the application of cool materials on the paved surfaces as mentioned above, and additionally the albedo increase of the building walls from 0.5 to 0.65 and of the building roofs from 0.5 to 0.9. The roofs' albedo was increased since all roofs of the study area are flat and at the same average height (≥ 16 m), thus not causing optical discomfort at the pedestrian level due to minimized reflections. Moreover, this albedo value was chosen in reference to the provisions of a relevant Greek building regulation (Article 8, Act no. $\Delta 6/B/14826$ "Measures for amelioration of energy efficiency in the public and private building sector", FEK B' 1122/17.6.2008).
3. The 'Vegetation' Scenario included: (a) coverage with vegetation of the UB courtyards at approximately 100% of the total area, (b) the tree planting of the courtyards with deciduous

species at least 25% (the 25% refers to the minimum ground surface shaded by the trees. The minimum shade provided on the ground level by a tree is reached when the solar radiation casts vertically to the tree canopy, i.e., at the maximum solar altitude. Therefore, the shaded ground surface equals the projected canopy surface [69]) of the total area, and (c) the tree planting across the sidewalks and pedestrian streets. Primarily streets oriented towards the E–W axis and with low H/W ratios were planted, i.e., those exposed more to sunlight. Trees of already existing species in the case studies were planted. In the courtyards, the tree species chosen to be planted were *Morus Alba* and *Cercis Siliquasirum*, which can provide sufficient shade. These trees were planted according to the solar study and towards the N–S axis. In order to protect the pedestrian zones from the prevailing winter winds (NE), rows of evergreen trees were planted towards the wind direction. The same methodology in tree planting was applied to the Agios Nikolaos Square included in the selected urban neighborhood but modified a bit. Specifically, the coverage with vegetation was at least 30% of the square's total area, and the tree coverage was at least 20% due to leaving uncovered space for the particular uses of the Agios Nikolaos Cathedral.

4. The *Final Scenario*—‘Vegetation, cool materials and albedo increase’ (Figures A2 and A3). This scenario is a combination of the abovementioned scenarios. Primarily the strategy referring to the vegetated surfaces increase and adequate tree planting was applied. Consequently, the conventional materials of the remaining hard and impervious surfaces (sidewalks, streets) were substituted with cool materials. Finally, the albedo of the building envelope was increased as proposed above.

Table 6. The examined scenarios.

The Examined Scenarios
‘Cool Materials’ Scenario: Cool, light-colored concrete tiles at the paved and impervious surfaces (up to 0.77 albedo, 0.90 emittance approximately) Cool asphalt at the streets (up to 0.55)
‘Cool Materials and Albedo Increase of the Building Envelope’ Scenario: Cool, light-colored concrete tiles at the paved and impervious surfaces (up to 0.77 albedo, 0.90 emittance approximately) Cool asphalt at the streets Albedo increase of the walls from 0.5 to 0.65 Albedo increase of the roofs from 0.5 to 0.90
‘Vegetation’ Scenario: Coverage with vegetation of the urban block courtyards at 100% approximately of the total area Tree planting of the courtyards with deciduous species at least 25% of the total area Tree planting across the sidewalks and pedestrian streets
‘Final Scenario—‘Vegetation’, cool materials and albedo increase of the building envelope’: The ‘Vegetation’ scenario combined with the ‘Cool materials and albedo increase of the building envelope’ Scenario

2.7. The Case Studies

The study took place in the center of the coastal Greek city of Volos (latitude 39.29°N, longitude 22.56°E). The selection of the case study area was based on two components: (a) the common shared urban morphology of central areas in Greek cities, and (b) the proven need for the areas’ environmental upgrade. Several studies focused on the air pollution problem [81,82] and on the Urban Heat Island effect in the city center of Volos [6].

The center of Volos is characterized by high building density and scarce open spaces and green spaces. A typical geometric grid constitutes the street pattern of the central area (Figures 1c and 5b). In this central area (Figure 5b), three sites were selected: (a) two urban blocks (UBs) typical of the urban fabric, and (b) a neighborhood: a cluster of 37 urban blocks with the public square of Agios Nikolaos (URBAN) (Figure 5c). Both UBs have similar orientation in the NE–SW axis, construction and paving materials (cement, asphalt, etc.), with the exception of two medium-sized existing trees in the UB.A’s courtyard. They differ mainly in terms of geometry and surface area, namely: (a) the

UB.B has a rectangular shape and UB.A has an orthogonal shape, (b) the length to width ratio is 3:4 for UB.B instead of 1:4 for UB.A, and (c) the UB.B courtyard covers a surface area corresponding to $\frac{1}{4}$ of the UB.A courtyards' surface area (Tables 7 and 8).

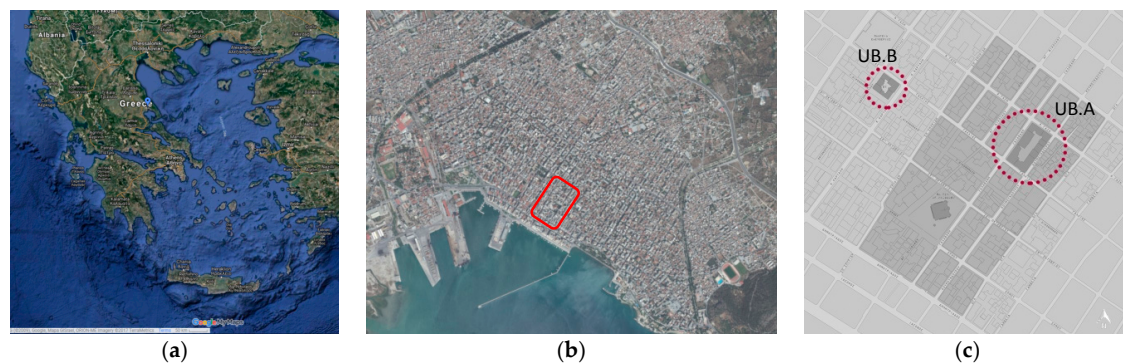


Figure 5. (a) The city location; (b) the selected central urban area; (c) the case studies: the two urban blocks (UB.A, UB.B) and the urban neighborhood (source: google earth, www.ktimatologio.gr).

Table 7. The urban geometry of the case studies.

Urban Geometry	Case Studies		
	UB.A	UB.B	URBAN
Total surface area	3780 m ²	1537 m ²	103,800 m ²
Surface area of the open spaces—void lots	846 m ²	225 m ²	25,950 m ²
Average building height	~16 m	~17 m	~17 m
Building height to street width ratio (H/W) ¹	1.5	1.8	1.8
Building height to open space width ratio	1.0	1.2	—
Length to width ratio of the urban blocks courtyards	1:4	3:4	—

¹ Urban geometry is often expressed with the Aspect Ratio Height/Width (H/W), which refers to the ratio of the mean building height to the streets' width (or generally to their mean in-between distance) (initially introduced by Oke, 1987). Thus, the H/W ratio describes how densely buildings are spaced with respect to their heights [35,83].

Table 8. The aspect ratio height/width (H/W) in the studied urban blocks.

Urban Geometry	Aspect Ratio Height/Width H/W ¹			
	Urban Block UB.A		Urban Block UB.B	
Northwestern Street Canyon (NW)	1.35		1.3	
Northeastern Street canyon (NE)	1.45		2.4	
Southeastern Street canyon (SE)	1.5		1.2	
Southwestern Street canyon (SW)	1.6		2.1	
Courtyard	1.0		1.2	

¹ Urban geometry is often expressed with the Aspect Ratio Height/Width (H/W), which refers to the ratio of the mean building height to the streets' width (or generally to their mean in-between distance) (initially introduced by Oke, 1987). Thus, the H/W ratio describes how densely buildings are spaced with respect to their heights.

3. Results and Discussion

3.1. Urban Blocks: UB.A and UB.B

The simulation results of the various scenarios examined in the two typical urban blocks UB.A and UB.B are as follows. Specifically, the air temperature, the surface temperature and the relative humidity fluctuation in the urban blocks and in the selected case study points (Figure 6) for all studied scenarios are depicted in Figures 7–9



Figure 6. The Urban block points where the receptors were set to collect simulation data in the ENVI-met model: (a) Urban Block B (UB.B) and (b) Urban Block A (UB.A).

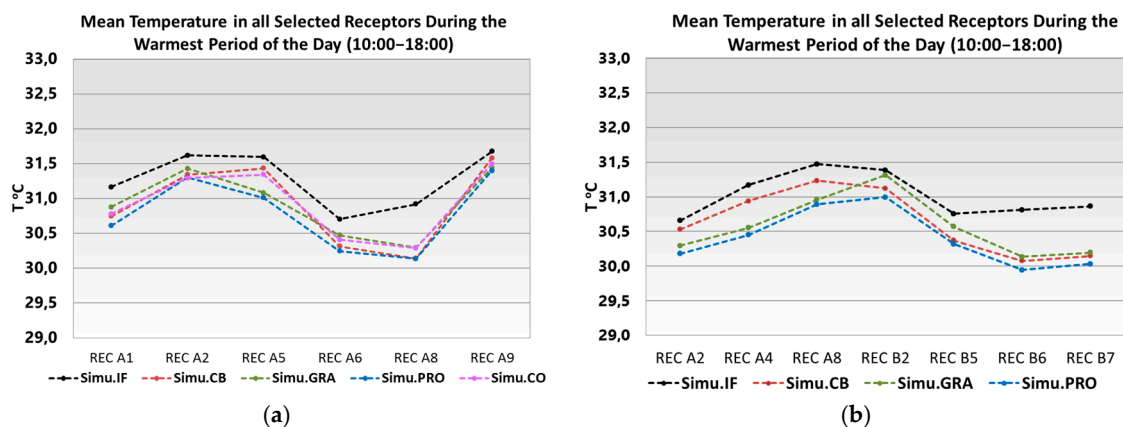


Figure 7. The average air temperature at 1.80 m height at the selected case study points for all examined scenarios of UB.B (a) and UB.A (b). The scenarios are: ‘Cool Materials’ (Simu.CO), ‘Cool Materials and Albedo Increase (Simu.CB)’, ‘Vegetation (Simu.GRA)’, and ‘Vegetation, Cool Materials and Albedo Increase (Simu.PRO)’.

More specifically for every single scenario the simulation results are summarized below.

3.1.1. The Effect of Cool Materials (UB.B)

The typical Urban Block B (UB.B) constituted the block with the smallest dimensions examined and as a consequence the smallest simulation model. Therefore this scenario was examined only on it. The use of cool, light-colored concrete tiles at the impervious paved surfaces of the UB.B contributed to a reduction of the surface temperatures up to 11 °C. The highest surface temperature decrease was estimated to be 16.3 °C in the courtyard, corresponding to a percentage change of 34%. The surface temperature slightly decreased down to 3.5 °C in A2 and A9 points (Figure 6). The latter is located in a street canyon with low aspect ratio (H/W) and is also exposed to solar radiation most of the day (10:00 am–17:00 pm) (Table 8, Figure A1).

3.1.2. The Effect of Cool Materials and Albedo Increase (UB.B and UB.A)

The use of cool paving materials, combined with the albedo increase of the building roofs and walls, proved to be slightly more effective in the UB.B microclimate improvement than the single ‘Cool Material Scenario (Simu.CO)’. In UB.A a major surface temperature decrease of 12.3 °C was also detected in the courtyard, meaning a decrease of 26%. In the street canyons around the UB.A the surface temperature decreased by 1.2–3 °C during the day (Figure 8). The overall improvement of the microclimatic parameters and the thermal comfort index was minimal.

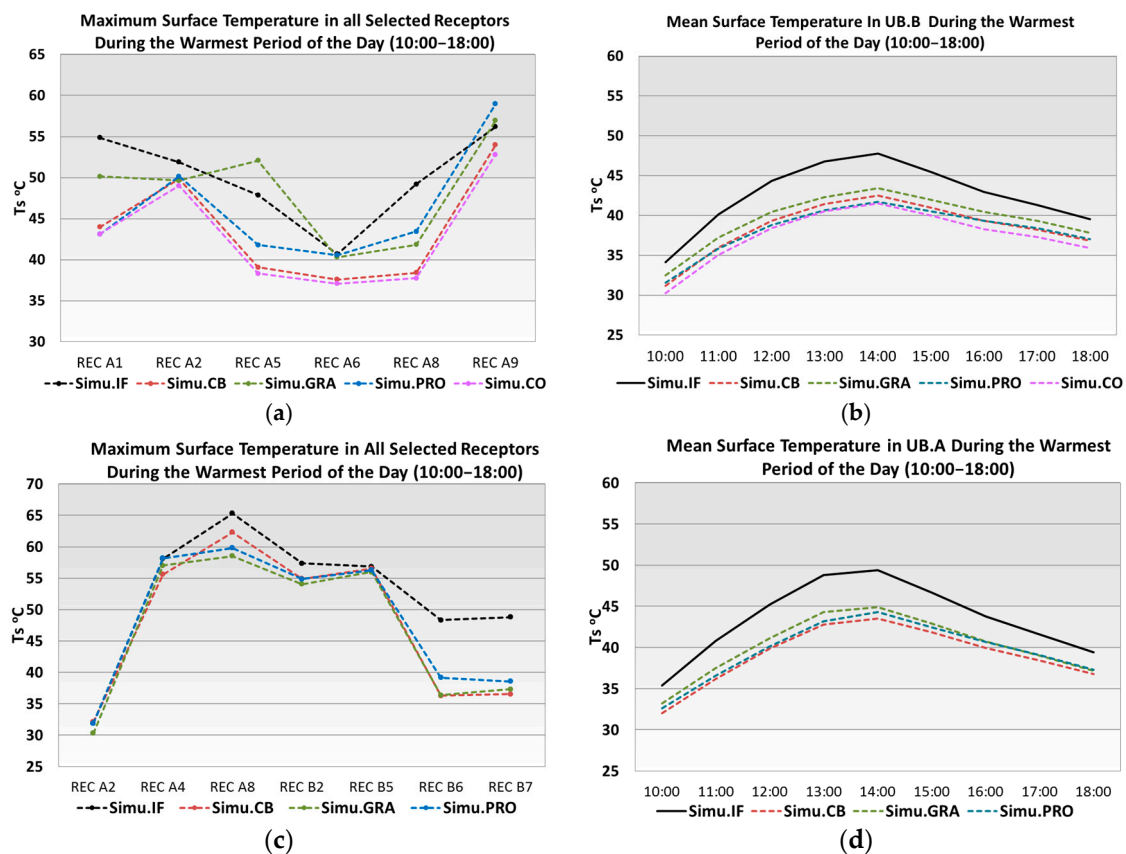


Figure 8. The maximum and average surface temperature in the selected case study points for all studied scenarios of UB.B (a,b) and UB.A (c,d).

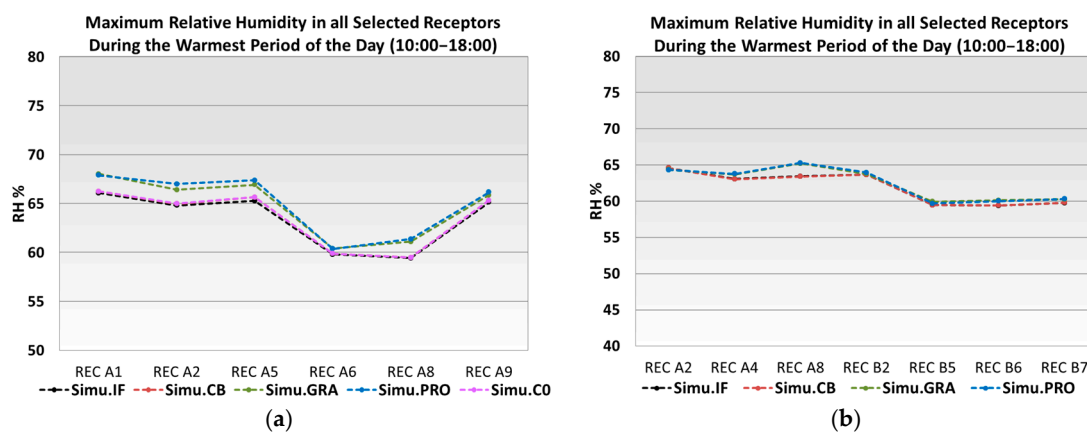


Figure 9. The maximum relative humidity at 1.80 m height at the selected case study points for all studied scenarios of UB.B (a) and UB.A (b).

3.1.3. The Effect of Vegetation (UB.B and UB.A)

In the case of the ‘vegetation’ scenario, all the examined microclimate parameters and the thermal comfort index were significantly ameliorated compared to the previous ones. The influence of vegetation and the shading effect through tree planting contributed primarily to courtyard microclimate improvement and secondly to the street canyon microclimate (Figure 10).

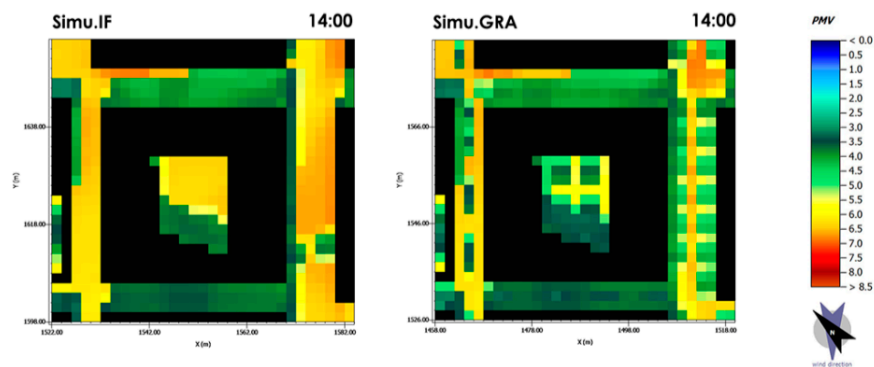


Figure 10. The PMV index spatial distribution for the ‘Initial Reference State (Simu.IF)’ of UB.B and for the ‘Vegetation Scenario’ (Simu.GRA) at 14:00 pm.

Moreover, the vegetation contributed to a noticeable increase in relative humidity. The highest increase of relative humidity was observed in the UB.B courtyard and was of 4.3 percentage units, corresponding to an increase of 11%. In the street canyons around UB.B the maximum humidity increase was estimated from 1.7 to 3.0 percentage units) (Figure 9a). In the UB.A the simulation results were similar to UB.B, namely higher relative humidity values were identified in the courtyard (up to 3.7 units) compared to the street canyons (0.4 to 2.9 units). In this case smaller increases were observed due to UB.A already having a large number of trees by the existing sidewalks. The relative humidity increased by up to 3.7 units in the courtyard, while in the street canyons this increase varied from 0.4 to 2.9 units (Figure 9b).

3.1.4. The Combined Effect of Vegetation, Cool Materials, and Increased Albedo (UB.B and UB.A)

The final and combined proposed scenario resulted in the most effective heat mitigation strategy in both urban blocks (UBs). Similarly to the ‘vegetation scenario’, this ‘final scenario’ proved to be more effective in the UBs’ courtyard microclimate. However, this strategy improved all basic microclimatic parameters and the thermal comfort index in a more effective way than all single techniques adopted in the previously examined scenarios.

More precisely, in this final scenario the ambient temperature values on the pedestrian level dropped down to 1.2 °C in the courtyard, and from 0.5 °C to 1.0 °C in the street canyons around the UB.B. The maximum temperature decrease in the street canyons was noted at point A5, where the aspect ratio (H/W) was relatively high (Table 8) and the tree planting was also increased. Similarly, in the UB.A the ambient temperature values on the pedestrian level decreased to 1.6 °C in the courtyard, and decreased by 0.6 °C–1.1 °C in the street canyons (Figure 7, Figure A4).

The surface temperature was significantly decreased in the final scenario as in all proposed scenarios and particularly in the UB courtyards. The highest decrease in the UB.B courtyard was estimated at 16.3 °C for the ‘cool materials scenario’ and 11.5 °C for the ‘final scenario’, corresponding to an overall decrease of 50% and of 31%, respectively. The surface temperature in UB.A was also notably decreased in all scenarios and especially inside the courtyard, where the maximum decrease fluctuated from 12.2 °C to 13.8 °C in the proposed scenarios (Figures 8 and 11).

The relative humidity values differed negligibly in the various proposed scenarios. The relative humidity was estimated to be higher in the final and in the ‘vegetation scenario’, where the vegetation was enriched and particularly where trees were planted. In the UB.B courtyard the relative humidity increased by up to 4.8 percentage units at the ‘final scenario’ (Figure 9a). In the street canyons around UB.B the relative humidity increased from 1.7 to 3.7 percentage units. Likewise, in the UB.A courtyard relative humidity rose by 4.3 percentage units in the ‘final scenario’. In the UB.A street canyons an increase of up to 3.3 percentage units was detected (Figure 9b).

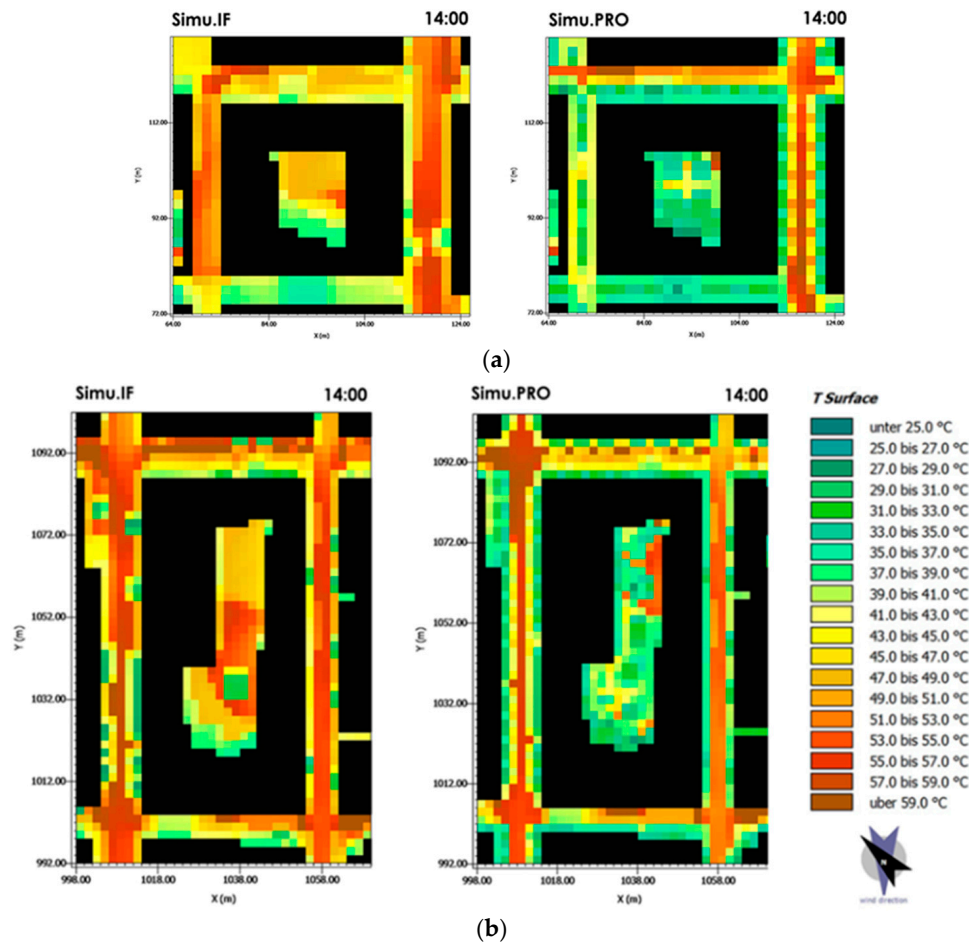


Figure 11. The spatial distribution of surface temperature at 1.80 m height in UB.B (a) and in UB.A (b) at 14:00 for the 'Initial Reference State (Simu.IF)' and for the 'Final Scenario (Simu.PRO)'.

The wind speed at both UBs and at the reference height of 1.80 m was calculated as considerably low. This fact mainly reveals the influence of urban morphology and the high building density (Table 8) in the wind field. In the case of the courtyards, this is undoubtedly due to the enclosed geometry of the space and the simultaneous absence of side openings, which prevent the influx of wind and at the same time hinder the natural ventilation of the space. In the street canyons, the low wind speed is due to the urban morphology and the natural obstacles (i.e., trees) (Figure 12).

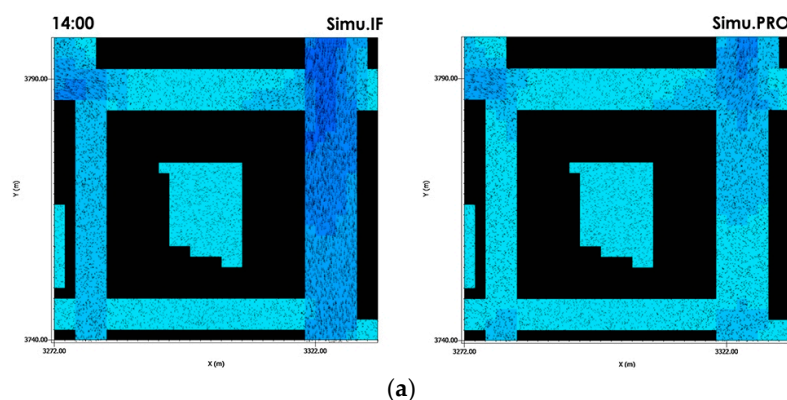


Figure 12. Cont.

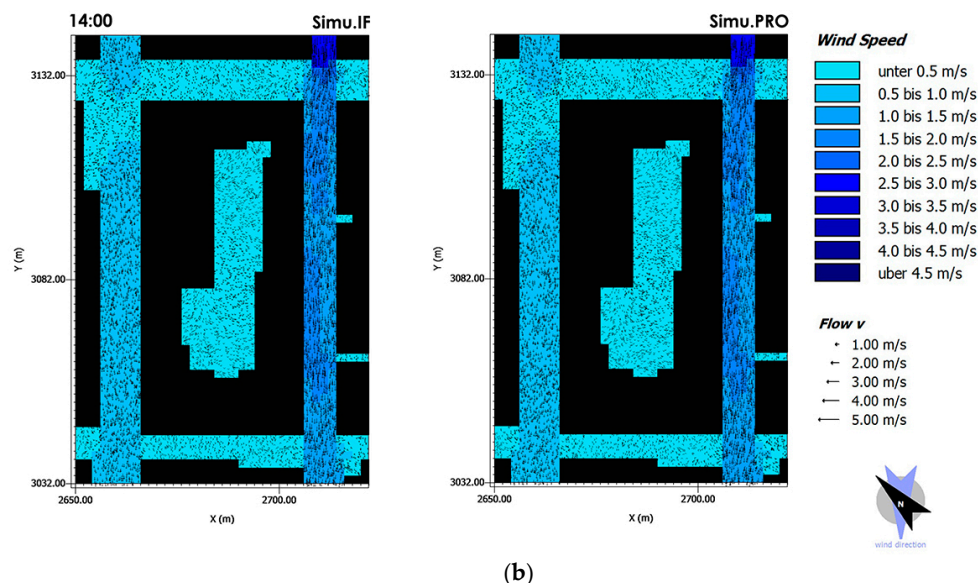


Figure 12. The wind flow field at 1.80 m height in urban block B-UB.B (a) and in urban block A-UB.A (b) at 14:00 for the ‘Initial Reference State (Simu.IF)’ and the ‘Final Scenario (Simu.PRO)’.

3.1.5. The Examined Thermal Comfort Index

The biometeorological PMV index, which combines a variety of parameters, was improved significantly not only in the case of the ‘final scenario’, but also in the ‘vegetation scenario’. Consecutively, all these parameters differentiate the PMV index not only in every single proposed scenario, but also in its distribution at the space.

As already stated and clearly shown in the diagrams, the final combined scenario was proven to be the most effective strategy at ameliorating the case studies’ microclimate. The microclimate improvement is depicted in the spatial distribution maps of the PMV index and particularly in the case of: (a) the UB courtyards with vegetated surfaces and trees, and (b) well-shaded open spaces (depending also on the duration of the spaces’ exposure to sunlight) (Figure 13). The PMV index at some points and restricted areas of the case studies exceeded the original data scale of the index. This can be considered acceptable since the index is calculated via ENVI-met software. High values of PMV index exceeding the original Fanger scale were identified in several studies where the ENVI-met model was used. In the Fahmy and Sharples [48] study in an urban neighborhood in Cairo, Egypt, PMV values were estimated up to +8. Similarly Berkovic, Yezioro, and Bitan [47] estimated PMV values higher than +4 while studying the thermal comfort conditions inside an urban block courtyard in a Mediterranean city. Furthermore, Ghaffarianosein et al. [50] estimated values of PMV index up to +6 in five urban block courtyards with different orientations in Kuala Lumpur.

Several worldwide studies regarding the microclimate of urban block courtyards have detected similar thermal comfort conditions to those detected in the current study. In Chatzidimitriou and Yannas’ [60] research, the courtyard of a typical urban block in Thessaloniki presented an analogous microclimatic profile. In this research, the effect of various bioclimatic interventions on the UB courtyard microclimate was studied. These interventions included the surfaces’ albedo increase from 0.5 to 0.7 and the substitution of the concrete paving surfaces with vegetation, including tree planting. These techniques resulted in an ambient temperature decrease of 0.2 to 0.7 °C. A slight microclimate improvement was detected when water bodies were introduced in the courtyard, as well as in the case of creating openings on the ground floor level [60].

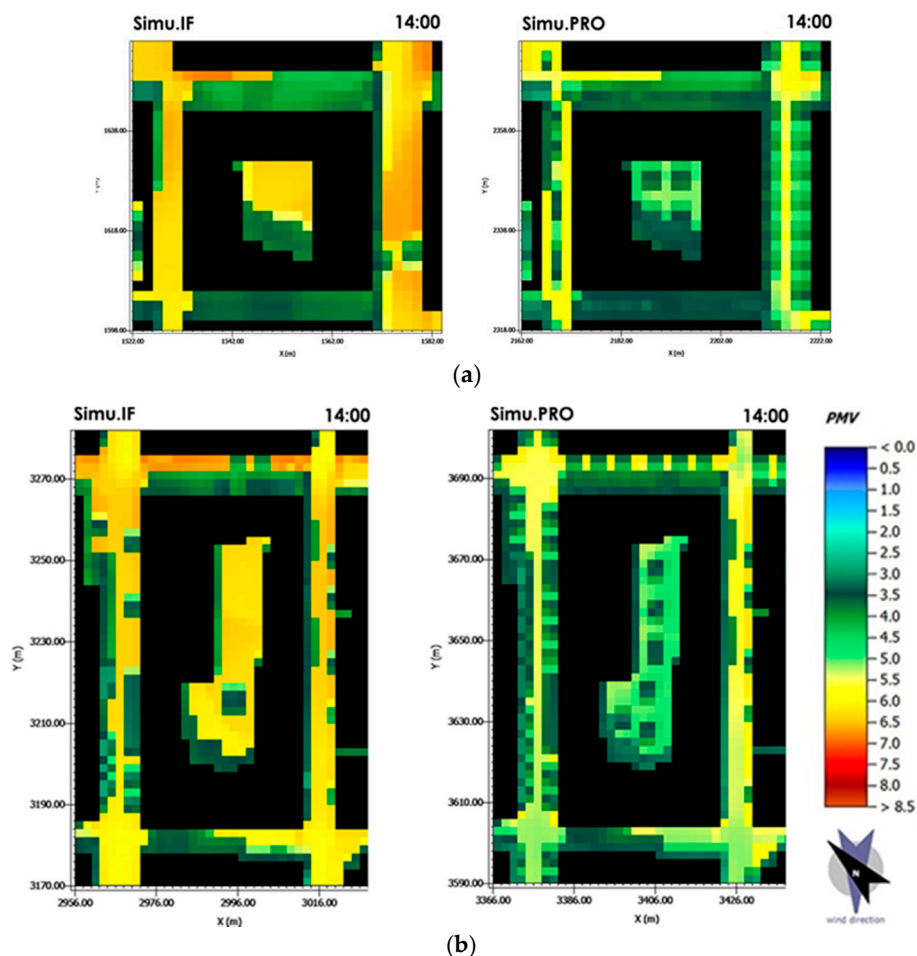


Figure 13. The spatial distribution of PMV index at 1.80 m height in UB.B (a) and in the UB.A (b) at 14:00 for the ‘Initial Reference State (Simu.IF)’ and the ‘Final Scenario (Simu.PRO)’.

Shashua-Bar et al. [84] studied two semi-closed courtyards in Negev, South Israel, which had the same orientation in the N–S axis, concrete pavements, and aspect ratio $H/W = 0.5$. Their proposed heat mitigation strategy based on using vegetated paving surfaces and trees for shading contributed to an ambient temperature decrease of 2°C . On the contrary, shading from textile tents instead of trees resulted in an increase of ambient temperature up to 1°C . The ground covering with vegetation in the absence of shading resulted in a slight temperature decrease [84].

Berkovic et al. [47] investigated the effect of various microclimate improvement interventions in urban block courtyards with different orientation. Tree planting and open galleries proved to be the most effective strategies for improving the courtyards’ microclimate. Specifically, tree planting versus N–S axis contributed to improving the thermal conditions more efficiently. On the contrary, natural ventilation through openings on a higher level than the ground floor in the courtyards resulted in hot air inflow and an increase of solar radiation access [47].

Similar to the aforementioned studies were the results of the Taleghani et al. [61] study, which studied several microclimate interventions in an urban block courtyard with the least favorable orientation (i.e., in W–E axis). They reached the following conclusions: (1) the introduction of a water body at 65% of the total surface area decreased the ambient temperature and mean radiant temperature, (2) the combined use of trees, vegetation, and ground surfaces resulted in decreasing ambient temperature and mean radiant temperature, and (3) the albedo increase from 0.55 to 0.93 resulted in increasing ambient temperature and mean radiant temperature. The latter was intensified

by the favorable orientation towards the sun in the E–W axis, contributing to a major exposure of the surfaces to solar radiation [61].

3.2. The Urban Neighborhood

The urban neighborhood scenarios (URBAN) were formed on the basis of the effect that every single intervention proposed in the abovementioned case study scenarios had on the local microclimate. Therefore, two scenarios were studied for the selected neighborhood regarding:

1. The combined effect of vegetation and cool materials (Figure A5b);
2. The combined effect of vegetation, cool materials, and building envelope albedo increase (Figure A5c).

The Figures 14 and 15 show the simulation results regarding the air temperature, the surface temperature and the relative humidity fluctuation in the urban neighborhood for the abovementioned scenarios.

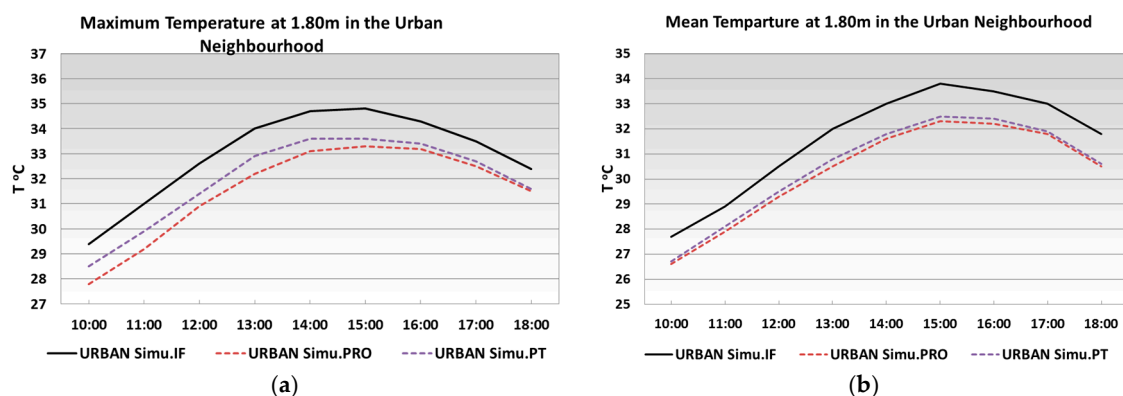


Figure 14. (a,b), The maximum and the mean temperature fluctuation at 1.80 m height in the urban neighborhood for the time period 10:00–18:00 and for all studied scenarios: (a) Initial Reference State (Simu.IF), (b) 1st Scenario (Simu.PT), and (c) Final Proposed Scenario (Simu.Pro).

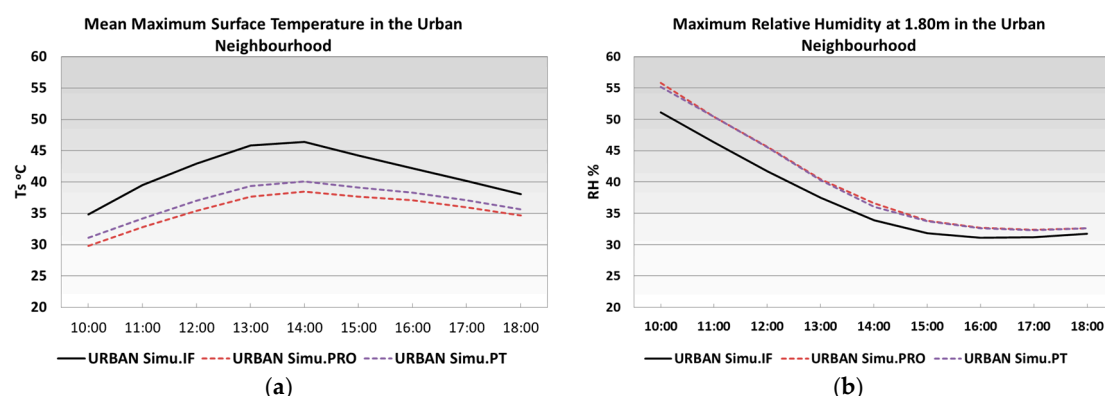


Figure 15. (a) The mean surface temperature in all studied scenarios in the urban neighborhood; and (b) The maximum relative humidity at 1.80 m height in all studied scenarios: (a) Initial Reference State (Simu.IF), (b) 1st Scenario (Simu.PT), and (c) Final Proposed Scenario (Simu.Pro).

3.2.1. The Combined Effect of Vegetation and Cool Materials

The 1st Bioclimatic Renewal Scenario for the urban neighborhood resulted in a remarkable improvement of the local microclimate parameters and the thermal comfort indexes. The application of this scenario on a cluster of 38 urban blocks contributed to a maximum temperature fall to 1.2 °C for

the warmest diurnal period (10:00–18:00), while the mean diurnal temperature fell 1.1 °C on average (Figure 14). The relative humidity increased up to 4.1 percentage units, namely increased by 8.0% (Figure 15b).

The mean maximum surface temperature dropped nearly 6.4 °C in total. The surface temperature is a parameter varying in space according to the surface material and the surface exposure to solar radiation. Therefore, the maps of spatial distribution extracted by the ENVI-met model give a more complete picture of the surface temperature differentiation and the total change compared to the initial conditions (Figure 16a). For instance, the surface temperature fluctuated between 33.0 °C and 39.0 °C at 15:00 in the final scenario, compared to 37.0 °C–53.0 °C in the reference initial state. The overall improvement of the microclimate parameters resulted in an improvement of the thermal comfort index. The PMV index improved further, as is clearly shown in the spatial distribution maps (Figure 16b).

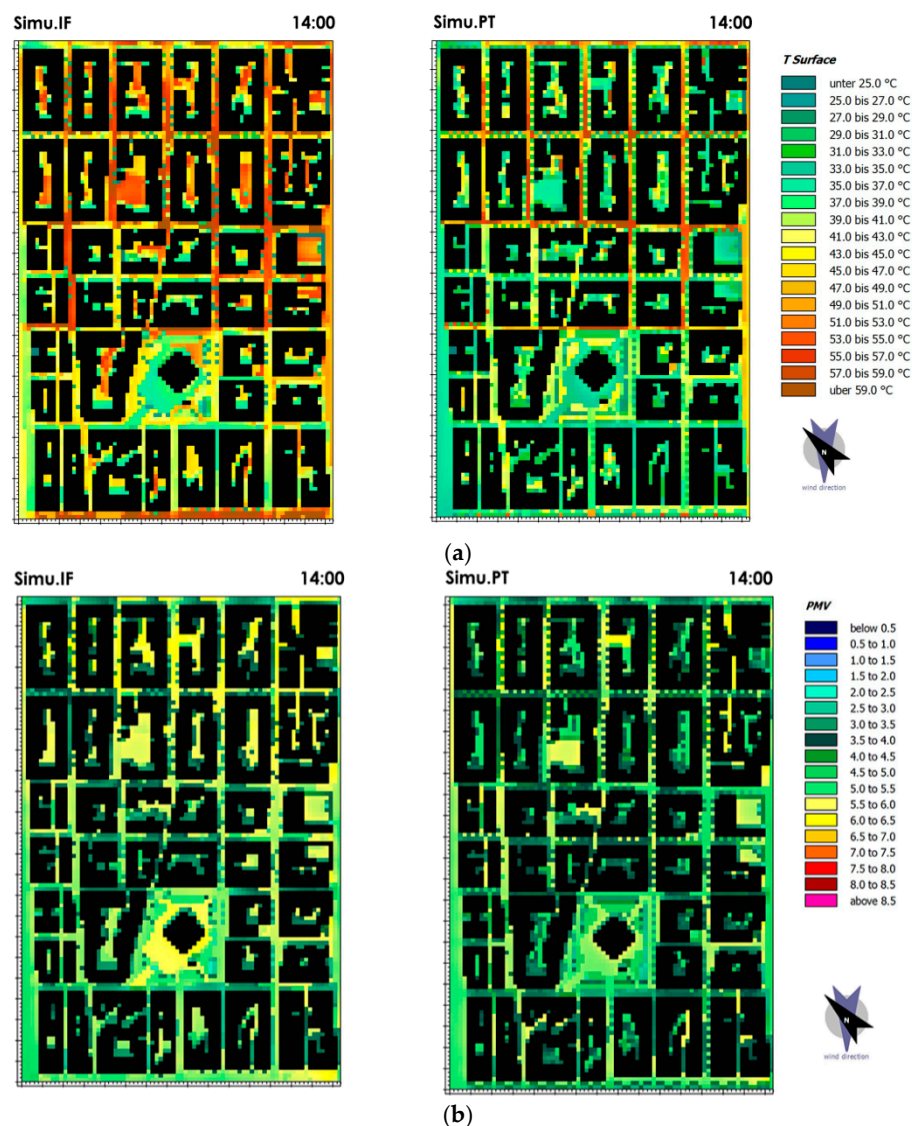


Figure 16. (a) The spatial distribution of surface temperature at 14:00, and (b) the spatial distribution of PMV index at 1.80 m height in the Urban Neighborhood at 14:00 for the 'Initial Reference State (Simu.IF)' and for the 'Vegetation and Cool material Scenario (Simu.PT)'.

3.2.2. The Combined Effect of Vegetation, Cool Materials, and Albedo Increase of the Building Envelope

The second and final scenario, compared to the first, differs in terms of: (a) the increase of the building roof and wall albedo, (b) the substitution of asphalt with cool concrete tiles at low-traffic streets (mainly those surrounding the public square), (c) a more careful addition of the trees, taking into consideration not only the necessary planting distances but also the lower grid resolution of the model ($dx = dy = 4$ m instead of $dx = dy = 2$ m used in the other case studies).

The final bioclimatic renewal scenario for the urban neighborhood proposed the most effective heat mitigation strategy for the urban neighborhood. The simulation results of the basic parameters and their spatial distribution in the total area of the studied urban site proved to be the significant positive effect of the proposed interventions on the local microclimate. The maximum temperature decreased to 1.8 °C during the warmest period of the day, while the mean maximum temperature decreased to 1.6 °C and the mean hourly temperature for the warmest period of the day decrease of 1.3 °C (Figure 14).

The addition of vegetation contributed to an overall increase of relative humidity up to 4.7 percentage units, thus 9.0% approximately (Figure 15b). It is worth mentioning that in several Greek cities this percentage might have been higher, but Volos already has a large amount of tree-lined streets.

In the wind flow field, both in this and the previous scenario, remarkable changes were not identified since the densely built urban site remained unchanged. Small changes in the wind flow field were detected at single points, namely where trees were added (Figure 17).

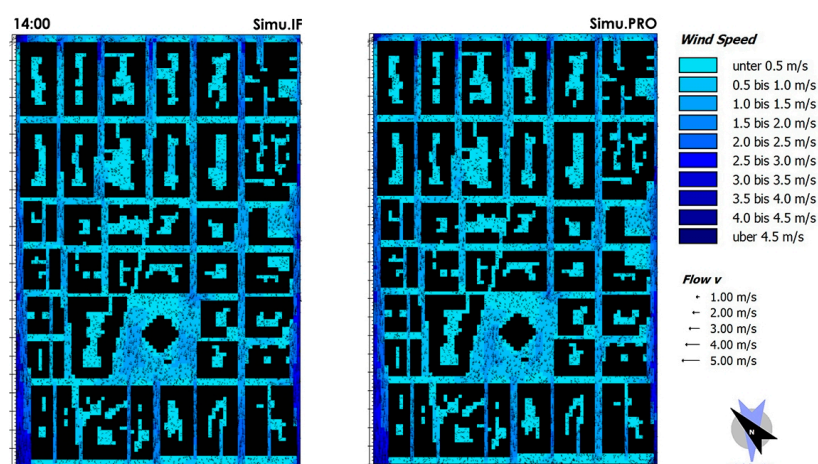


Figure 17. The wind flow field at 1.80 m height in the urban neighborhood at 14:00 for the ‘Initial Reference State (Simu.IF) and the ‘Final Scenario (Simu.PRO)’.

The surface temperature decreased to 8.1 °C in the whole urban area (Figure 15a). Specifically, it decreased further where: (a) vegetation and pervious surfaces were added, (b) common asphalt streets and pedestrian zones were paved with cool materials, and (c) shaded surfaces resulted from tree planting. The surface temperature decrease is more evident in the spatial distribution maps. For instance, at 14:00 in the afternoon, the surface temperature in the final scenario ranged from 35 °C to 43 °C, whereas in the initial conditions it ranged from 35 °C to 57 °C (Figure 18).

As a consequence, the selected thermal comfort index was more efficiently improved in the ‘final scenario’ for the urban site compared to the single studied urban blocks (UBs). The PMV index was remarkably improved, as is depicted in the maps below. Despite the fact that the PMV index might be high at some single points in the case study area, in general this index was improved for most of the urban sites. At 14:00, the PMV index for the initial conditions ranged from 3.5 to 6.0, with the most prevalent values being from 5.0 to 6.0. At the same time, the PMV index in the ‘final scenario’ ranged

from 2.5 to 5.0, with the most prevalent values being from 3.0 to 4.5, corresponding to a 25% change (Figure 19).

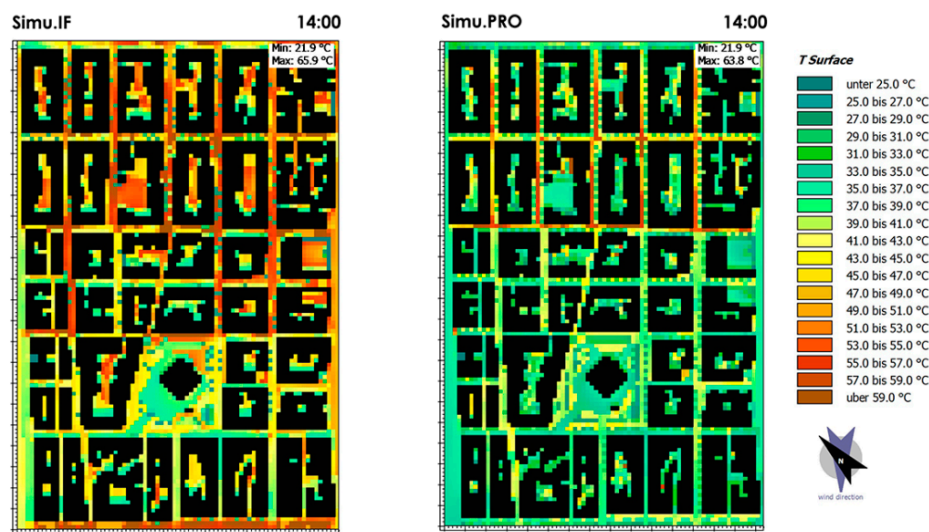


Figure 18. The spatial distribution of surface temperature at 14:00 for the 'Initial Reference State (Simu.IF)' and the 'Final Proposed Scenario (Simu.Pro)' in the urban neighborhood.

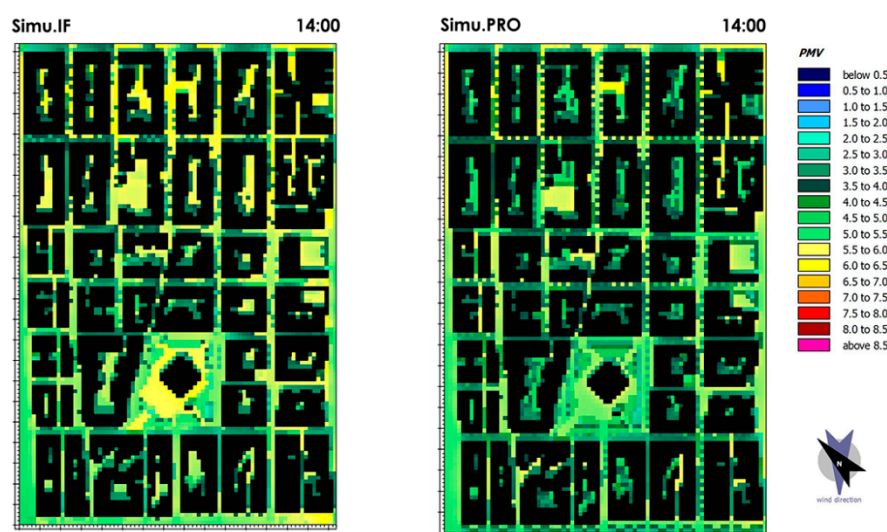


Figure 19. The spatial distribution of PMV Index at 1.80 m height in the urban neighborhood at 14:00 for the 'Initial Reference State (Simu.IF)' and for the 'Final Scenario—vegetation, cool materials and albedo increase of the building envelope (Simu.PRO)'.

Therefore it is proven that the bioclimatic interventions on a scale larger than that of a single UB, as on the urban neighborhood scale, can have a greater positive effect on the microclimate of densely built-up Greek city centers.

Similar bioclimatic renewal interventions on large urban sites in densely built city centers are scarce, particularly in Greece. In Marousi, Attica, at a 16,000 m² urban surface the substitution of conventional paving materials with natural and cool materials took place. More specifically, the conventional materials were asphalt and concrete tiles. The natural and cool materials were marble and cool concrete tiles. This heat mitigation technique contributed to an ambient temperature decrease from 1.2 °C to 2.0 °C [85]. In the research paper of Fanchiotti et al. [20], the surface albedo of a central

urban area of 500,000 m² in Rome was increased. This albedo increase caused an ambient temperature reduction down to 3.0 °C.

Shahidan et al. [31] studied three different bioclimatic renewal scenarios of a 420,000 m² boulevard in the city center of Putrajaya in Malaysia. These scenarios included interventions such as: (a) planting light foliage trees on 50% of the total surface area, (b) planting dense foliage trees on 50% of the total surface area, and (c) the use of high albedo paving materials (0.8) combined with planting dense foliage trees on 50% of the total surface area. The maximum ambient temperature decrease was estimated at 1.5 °C for the third scenario, while the contribution of using only high albedo materials in the temperature decrease was estimated at 0.2 °C [31].

4. Conclusions

The bioclimatic renewal interventions examined in this research were applied from the single urban block to the urban neighborhood. This fact is of high importance because the same strategies were adopted on two basic spatial scales, i.e., the urban block—the main structural element and organizing cell of the city, and the urban neighborhood, defined as a cluster of urban blocks.

It is worth mentioning that the examined bioclimatic renewal strategies could be considered as moderate since the interventions proposed did not include construction, building interventions, or techniques based on the use of renewable energy sources. In all case studies the final proposed scenario (vegetation, cool materials, and increased albedo) resulted in the most effective heat mitigation strategy. The ‘vegetation-based scenario’ also contributed to a significant microclimate improvement in the case studies. In general, the outdoor thermal conditions were observed to be improved in the urban blocks’ enclosed courtyards compared to the street canyons around the urban blocks due to adding vegetation and solar radiation control through tree planting (Figure A1).

As already stated, the benefits of the bioclimatic interventions included in the final scenario were magnified when these were applied on a spatial scale larger than that of the single urban block. Therefore, the ‘final scenario’, when applied to an urban neighborhood (104 acres), proved to be even more effective in terms of local microclimate improvement. The microclimate parameters and, as a consequence, the selected thermal comfort index were estimated to have significantly improved both from the initial reference condition and the single urban blocks. The maximum temperature decrease of 1.8 °C and the mean temperature decrease of 1.3 °C average it a neighborhood in the densely built-up center of a Mediterranean city cannot be considered negligible (Table A1).

If the various bioclimatic renewal strategies are implemented on a larger spatial scale than that of the single urban block, the benefits on the local microclimate are magnified. This microclimate improvement was due to moderate bioclimatic interventions, as mentioned above. Therefore, the proposed moderate bioclimatic renewal scenarios and particularly the ‘final combined scenario’ proved that they can constitute tools for the environmental upgrade of urban sites with numerous urban blocks in the densely built centers of Greek cities.

Hence, upon completion of the pilot implementation of the present research methodology, it becomes evident that more accurate and well-documented measures and urban policies can be proposed for the case study area from urban planners, designers, and policy makers. An advantage of the current methodology is the two spatial scale approach, which constitutes a useful urban policy tool. Additionally, the methodology can be easily adopted in any city due to being organized in a simple and generalized mode. Furthermore, it takes into consideration particular features of a city such as the urban morphology and climatic conditions. To this end, urban design can be more efficiently directed towards creating climate-responsive urban environments, which are a necessity given the current situation of climate change [86].

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. The microclimate improvement in the case studies.

Microclimatic Parameter Improvement in the CASE STUDY SITES					
Estimated Parameters at 1.80 m Height	URBAN BLOCK TYPE A (UB.A)		URBAN BLOCK TYPE B (UB.B)		Urban Neighborhood (URBAN)
	Street Canyons	Courtyard	Street Canyons	Courtyard	Total Surface Area
Maximum Air Temperature Decrease	0.6–1.1 °C	1.2 °C	0.5–1.0 °C	1.2 °C	1.8 °C and 1.6 °C (maximum decrease of the mean hour temperature)
Maximum Relative Humidity Increase	1.4–3.3	4.2–4.3	0.7–3.7	4.8	4.7
Maximum Surface Temperature Decrease	0.1–8.2 °C	12.3–13.1 °C	0.7–12.7 °C	11.5 °C	8.1 °C (see. Spatial Distribution Maps)
Improved PMV Index	see. Spatial Distribution Maps of the PMV Index				

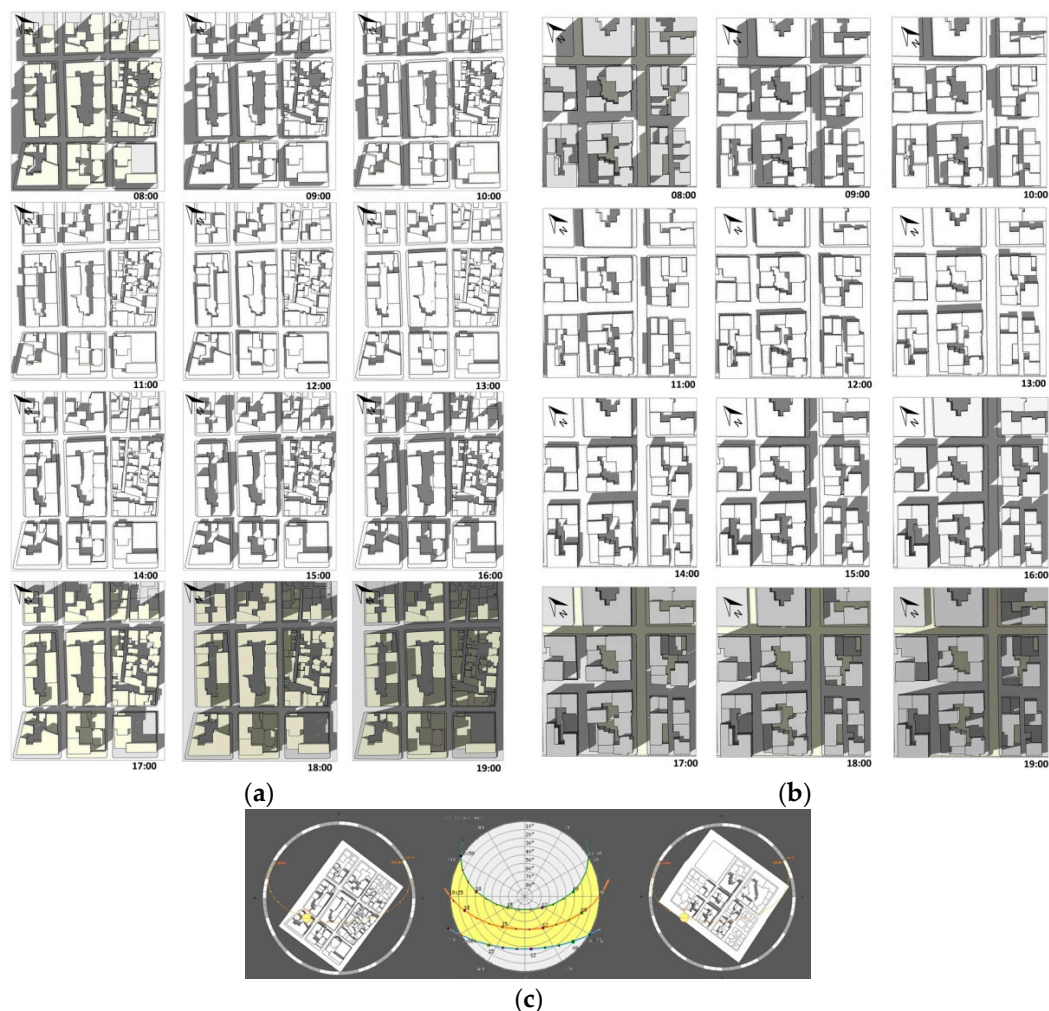


Figure A1. Shadow ranges of the two urban blocks on 20 June, from 08:00 to 19:00. The solar study was carried out by Autodesk Vasari software for the exact location of each block and for the latitude of Volos (c), (a) Urban Block A—UB.A, and (b) Urban Block B—UB.B.

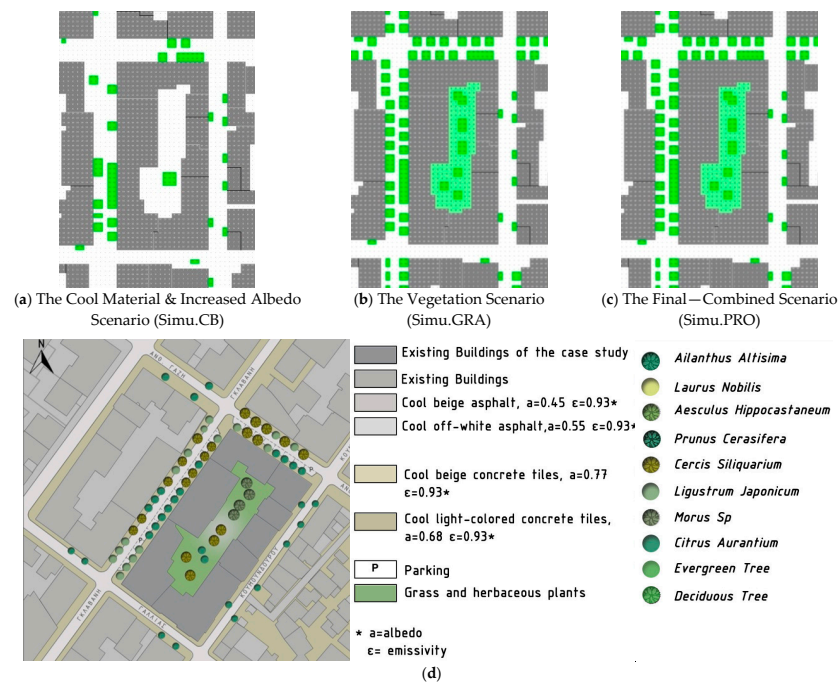


Figure A2. (a–c) The simulation models of the three examined scenarios for Urban Block A, and (d) the proposed interventions in the ‘final combined scenario’.



Figure A3. (a–d) The simulation models of the three examined scenarios for Urban Block A, and (d) the proposed interventions in the ‘final combined scenario’.

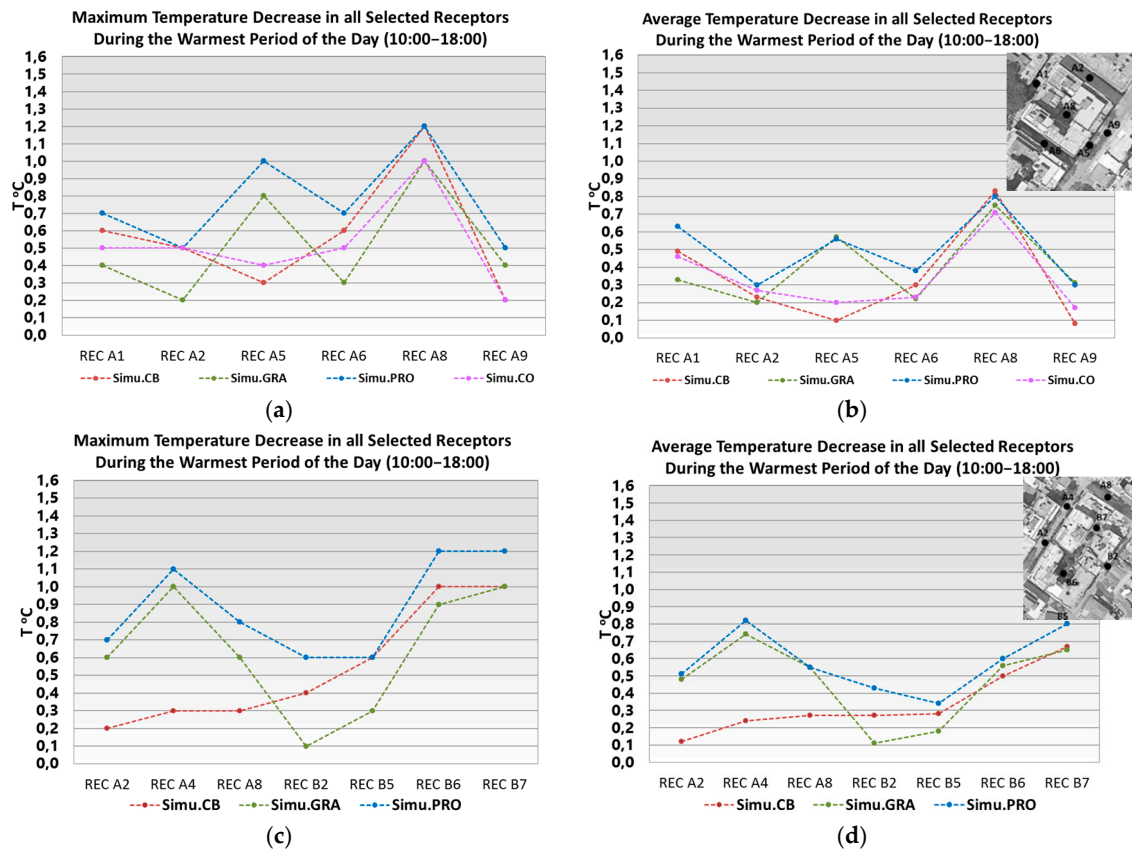


Figure A4. The maximum and average air temperature decrease at 1.80 m height in the selected points for all studied scenarios of UB.B (a,b) and UB.A (c,d).

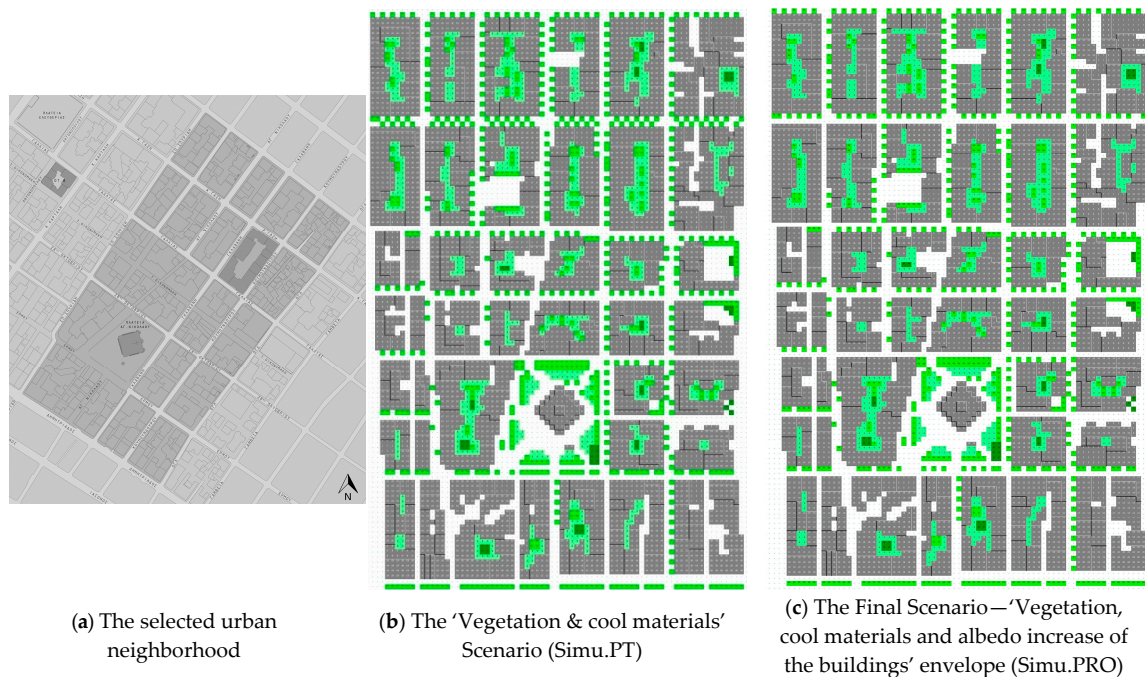


Figure A5. (a) The selected urban neighborhood (URBAN) in the city center; (b,c) the simulation models of the two examined scenarios for the urban neighborhood.

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