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The Thermal Comfort Problem in Public Space during the Climate Change Era Based on the Case Study of Selected Area in Lublin City in Poland

Natalia Przesmycka , **Bartłomiej Kwiatkowski** and **Małgorzata Kozak** *

Faculty of Civil Engineering and Architecture, Lublin University of Technology, Nadbystrzycka 40, 20-618 Lublin, Poland
* Correspondence: m.kozak@pollub.pl; Tel.: +48-726-651-113

Abstract: Noticeable climate change in recent years is reducing the comfort of public spaces in the urban environment, and is becoming an element of urban policies. The adaptation to climate change requires the development of new design guidelines for the development of public spaces. The appropriate definition of development density, choice of building materials, technologies, planting species, and the used directions is a challenge that depends on local conditions. A representative public space located in the area of a multi-family housing estate built in the second half of the 20th century in Lublin (Poland) was selected for the study. The space has undergone redevelopment twice in the last 10 years. The aim of the study was to determine to what extent the executed and designed changes actually improve the thermal comfort of users. Quantitative and qualitative indicators of the successive phases of the investment were analyzed in the context of projected climate change. The simulation was developed using the ENVI-met version 5.0 software. As a result of the changes made, there has been an improvement in usability and comfort. Five simulations were carried out for the warmest day of the year for one of the public spaces in the city of Lublin. The sensation of PET thermal comfort was investigated for people aged 35 and 75, as a particularly sensitive group. The obtained result proved that the elderly feel higher temperature rates than younger people. In one of the simulations, new plantings were proposed to improve the local microclimate. The material temperatures of paved surfaces were also investigated. The article shows how the local microclimate and people's desire to stay in a given space can be improved with new tree planting.

Keywords: climate change; public space; heat losses and gains; ENVI-met; human thermal comfort thermal properties of materials

Citation: Przesmycka, N.; Kwiatkowski, B.; Kozak, M. The Thermal Comfort Problem in Public Space during the Climate Change Era Based on the Case Study of Selected Area in Lublin City in Poland. *Energies* **2022**, *15*, 6504. https://doi.org/10.3390/en15186504

Academic Editor: Elena Lucchi

Received: 2 August 2022
Accepted: 2 September 2022
Published: 6 September 2022

1. Introduction

Climate change adaptation in cities is now an important challenge for European cities, and is becoming part of urban policies [1].

The urban heat island (UHI) is a phenomenon that further amplifies the negative effects of climate change. Densely built-up areas of development absorb and then radiate heat from the sun's rays, which, with the additional heat gained from anthropogenic activities, causes a local increase in temperature relative to neighboring undeveloped areas. This problem is being researched in many areas, and ways of mitigating this phenomenon are currently the most important challenge [2]. Recent studies show a significant influence of the city's morphology on the formation of this phenomenon, emphasizing the importance of 3D building forms, particularly tall buildings and trees [3]. The problem of mitigating UHI does not only relate to climate issues, but also to spatial planning—on the one hand, indicating polycentric urban systems as the most vulnerable [4], whereas the spatial policy of most European cities aims to reduce urban sprawl and suburbanization. In this context, the problem of a possible improvement of local thermal conditions in already-invested areas comes to the fore. UHI areas reduce environmental quality. Pollution and thermal stress-related illnesses are increasing among the population, causing discomfort. They require more energy to be used in buildings [5]. The European Environment Agency's report, The European environment—state and outlook 2020 (SOER 2020), on the state of the environment in 2020 is not optimistic [6]. Adverse phenomena, such as heat waves, droughts, and torrential rains, increase the risk of flooding, and rising sea levels will accrue and intensify in future years. For city dwellers, the phenomenon that will most directly and significantly affect the physiologically equivalent temperature (PET) sense of human thermal comfort outdoors (HTCI) will be the increase in footnote temperatures. The perception of temperature by the user of a public space is directly related to how it is managed [7–10], whereas human thermal comfort outdoors itself inflicts a serious threat on public health issues [11,12].

Thus, the proper arrangement of public spaces, in particular through appropriately executed plantings, offers an opportunity to mitigate the future negative effects of climate change. Solutions to improve the quality of life in the public spaces of cities in Poland in the context of natural solutions (NbS) are low, as shown in a study performed in 2021. Polish city authorities often introduce natural solutions without knowledge and awareness of their classification and nomenclature. Urban municipalities with a higher budget per inhabitant, and the central and western part of Poland, have a higher environmental awareness [13].

The aim of this research was to test the appropriateness of the measures taken so far in the inter-block public space in the context of climate change, and to analyze how feasible solutions (such as planting greenery or introducing water) can influence temperature distribution. The authors wanted to draw attention to the problem of the relationship between the comfort of public space and the presence of trees in it. In Poland, there are still many public spaces in multi-family housing which do not have enough trees, and, thus, do not fulfil their function in summer. The ever-increasing proportion of paved surfaces (including impermeable surfaces) is also an aggravating circumstance. Another objective was to investigate the thermal comfort of users, especially seniors, as a vulnerable group. This applies to most housing estates built in the second half of the 20th century, whose residents are now among the "ageing population groups".

1.1. Literature Review

For several years now, we have been able to observe a growing interest among researchers in the notion of adapting public spaces to the challenges posed by progressive climate change [14]. Already at the end of the twentieth century, the importance of the local context and the urban scale of the areas under study was noted [15]. Today, the vast majority of research based on modelling techniques and change scenarios is conducted in Asia, China, and countries in warm climate zones. The topics of the research presented here necessitated, at first, the study of publications on climate change adaptation in European cities. A pilot study from Heidelberg, Germany, on a new sustainable urban quarter that experienced more pronounced heat stress than the historic city center (in the hot and dry summer of 2018) demonstrated the usefulness of an interdisciplinary approach to identify appropriate heat adaptation measures. The method presented, which is also based on a questionnaire survey of the perception of public spaces, showed how important it is to design them properly, facing not only climate change, but, above all, social expectations [16]. Similar results were obtained by Italian researchers, also indicating a lower tolerance of local environmental conditions by residents compared to tourists [17].

The urban heat island occurring in Polish cities in the context of climactic and urban conditions has been best recognized in Warsaw [3]. Experimental studies have shown that an increase in the number of lawns and trees and the implementation of green roofs in the center of Warsaw cause only small changes in the intensity of the urban heat island. In order for significant improvements to occur, some radical measures are needed, involving the reorganization of existing buildings.

The materials that buildings are made of are very important for the thermal balance of a city. They discharge part of the heat they accumulate into the atmosphere by radiation and convection, and absorb solar radiation. Solar reflectance and thermal emissivity are the most important factors on which the thermal performance of materials depends [18]. The Solar Reflectance Index (SRI) or albedo of a surface is the reflected portion of the incident solar radiation whose value is between 0 and 1 (or 100%) [19]. It is a measure of the reflectivity of sunlight and the emissivity of materials. It can be used as an index of how warm materials can get when sunlight falls on their surface [20]. Reducing the urban heat island effect is helped by the use of cool materials. These can be applied to pavements, roofs, and walls. The use of surfaces made of these types of cool materials can reduce the temperature by up to 7.6 °C in bright sunlight, as shown by a field study conducted in Athens [21]. Another study carried out in Rome shows that the application of cool materials can reduce the temperature by almost 10.0 °C [22]. Furthermore, the need to use air conditioning can be reduced by an average of 20% by using a cool roof. Cool roofs achieve better cooling results when they have an albedo $\geq$ 0.7. However, cool materials are exposed to the elements, so they lose their properties after a few years [23,24]. The most effective way to cool temperatures is through green infrastructure.

1.2. Greenery as a Solution in Climate Change Mitigation

Greenery should be identified as the most important element mitigating the phenomenon of urban heat island, local and sensible temperatures. Its influence on the aforementioned parameters always depends on a number of factors. Greenery is a desirable element of urban street furniture, fulfilling natural, compositional, and aesthetic roles, and influencing the microclimate of the place not only during the day, but also during the night [25]. The use of greenery is an indispensable element of urban revitalization and the improvement of thermal comfort in the space of historically shaped urban squares [26], as well as in the case of traditional quartered building layouts [27]. The direction of the street in relation to the world sides also has a real impact on the actual reduction of temperature and the feeling of comfort [28]. As shown in a study carried out in Łódź, the best temperature-lowering effects were observed by introducing greenery constituting 10% of the street canyon, in an east–west-oriented street canyon [25].

The most important of the factors causing the reduction of neighborhood temperatures by deciduous trees is their shading property. Field and simulation studies show that the effect of pavement albedo on thermal comfort is less than that of vegetation cover [29]. This is particularly relevant in the case of wider sustainability and energy saving. Studies have shown that the shading of buildings by trees results in real savings, due to the reduced need for air-conditioning of rooms [30]. Just behind the effect of shading by urban trees, researchers emphasize the real impact of the so-called cool surfaces (cool roofs and cool pavements) as having a significant impact on the air temperature in the city and, thus, being able to reduce energy consumption for cooling and smog.

The increase in temperatures is particularly acute in densely built-up, urban areas. The phenomenon of increased temperatures in built-up areas relative to rural areas has been observed for almost 200 years [31,32]. Nowadays, the heat island phenomenon is a popular research topic beyond climatology alone. In the case of Lublin, studies indicate that there has been a statistically significant increase in the average maximum temperature and the number of days with temperatures above 30 °C during the summer period. Heat waves lasting several days are becoming increasingly common [33]. Sometimes, the introduction of even small forms of greenery can improve feelings of thermal comfort. An interesting study looked at temporary forms of greenery in the center of Wrocław. The study analyzed the effect on thermal comfort of a green structure, which, if appropriately shaped, can create a new insulating shield for the human body by changing the temperature of the surrounding surfaces [34].

1.3. Characteristics of the Study Area

Lublin is located in the eastern Poland in a temperate climate zone. Its current population is estimated at around 320,696 (31 June 2022), with an area of 147.47 km^2 [35,36].

The area of the city is characterized by varied relief and altitude differences within the administrative boundaries, amounting to 75 m (from 236.5 m above sea level to 164 m above sea level). The city has three river valleys and a system of connecting dry valleys, which are the city's most important reservoir of open green areas. According to a 2021 study by the Institute of Urban and Regional Development, the percentage of publicly accessible green space of more than 1 ha available to residents within a five-minute walking distance is relatively low (36%, with a national average of 50%) [37]. Multi-family housing, in the form of housing estates dating from the second half of the 20th century, constitutes a large part of the functional and spatial structure of Lublin. This is in line with trends across the country, where, today, flats in prefabricated large-panel multifamily buildings are inhabited by around 12 million people (or around 30% of the population, as of 2018). The majority of the approximately 4 million flats in this stock were built in the 1970s [38]. At that time, the urban design of housing estates was based on standards that ensured accessibility to various forms of open space and public greenery.

Lublin is one of 44 Polish cities that have developed the Climate Change Adaptation Plan for the City of Lublin until 2030, which is part of the implementation of the provisions of the National Urban Policy [39]. The document, which was developed between 2017 and 2019, highlights that climate change is already noticeable: "Increases in temperature and changes in the nature of precipitation are significantly affecting hydrological systems and water resources, and extreme climatic and hydrological phenomena, such as the heat waves of 1994 and 2015, droughts (1991), floods (2006 and 2007), hurricane winds (in 2011, 2015 and 2017), adversely affect the health and living conditions of the city's inhabitants, the city's infrastructure and nature (...)". In Lublin, the following sectors are particularly vulnerable to the effects of climate change: public health and quality of life, water management, spatial management, and biodiversity. The City of Lublin is currently developing guidelines for the design of public spaces in the context of climate change adaptation, which could be applied in the provisions of local plans. This article presents the results of the research as a component of the development of the guidelines.

According to the table included in the Climate Change Adaptation Plan for the city of Lublin [39], until 2050, an increase in hot days and the intensity of heat waves is predicted. The prolongation of periods with daily temperatures exceeding 25 °C, as well as a decreasing trend of low temperatures in the winter period are the forecast.

The public spaces accompanying multi-family housing are the largest group of public spaces in Lublin. Their quality is directly linked to the sense of satisfaction with the standard of living in the city. At the same time, a problem is the overdevelopment, through the construction of multi-family houses in a developer system, located in the areas of residential squares [40]. This is a problem common to many European post-socialist countries in the so-called Eastern Bloc, e.g., Serbia [41] and Slovakia [42]. The study area concentrates the above-mentioned problems.

1.4. Transformation of the Study Area

The study area is located in the Bronowice district, which ranks 12th (out of 27) in terms of the index value of living conditions in the districts of Lublin [43]. The development of the district was created in two phases: in the 1950s, and at the turn of the 1970s and 1980s. The most recent developments came into being after 2008 as a result of the densification of the existing development layout in the area of former green spaces. Compared to the general population of Lublin, the residents of the Bronowice district have a more negative opinion of the availability of places for pleasant leisure activities. As in the city as a whole, the residents of the district most often indicated the need for new parking spaces and the development and adequate maintenance of green spaces [43].

The square included in the survey remained undeveloped until 2012, providing an open green lawn, a place to walk the dogs and play ball. The only element of tall greenery was a chestnut tree (*Aesculus hippocastanum*). Directly under the windows of the multi-family buildings, ornamental shrub and occasional tree plantings appeared as a result of the residents' own initiative.

In 2010, as a result of a grassroots initiative by residents, a recreational square was designed in half of the study area (western part), consisting only of paths, benches, pergolas, and plantings of low- and medium-ornamental greenery. At the time, the residents did not want any tree planting, and municipal policy did not focus on the problem of greenery or climate resilience. It is important to mention that it is only since 2017 that the so-called Green Civic Budget has been in place in Lublin, allowing participatory implementation of greenery management and new greenery projects submitted by residents. It was the first civic budget of this type in the country.

The next stage in the development of the area was the plantings in the left vacant eastern part. Unlike the design work carried out earlier, these were not the result of the residents' initiative, but the realization of replacement plantings carried out by the developer after dozens of mature trees on the same estate had been felled for a new housing development. The study field was the largest "empty" space located in the immediate vicinity.

The large number of trees planted in the square were, therefore, not created to combat climate change, but as a result of compensatory planting by the developer, who was ordered to do so in the neighborhood (109 deciduous trees and 220 shrubs) (Figure 1).

Figure 1. Several photos of the survey area, June 2022.

The planting designs were consulted with the neighborhood council in 2015, but there were clear voices of dissatisfaction among residents as the open space was eagerly used for games and outdoor activities by the residents [44].

2. Materials and Methods

2.1. Simulation Software

As a result of their analysis of the possibilities offered by the use of predictive analytics software for air temperature and mean radiant temperature by analyzing the coefficient of determination, mean squared error, and Willmott's consistency index, the authors of this article decided to choose ENVI-met software. ENVI-met is a software from the Computational Fluid Dynamics (CFD) group for numerical fluid mechanics simulations that allow the analysis of the relationship between airflow amongst buildings and greenery, the heat transfer processes of different surfaces, vegetation parameters, and pollutant dispersion in order to determine the values of thermal comfort indices [45].

The application, developed by the team of Prof. M. Brus from the University of Mainz, allows the creation of three-dimensional, non-hydrostatic microclimatic models using the finite difference method, simulating the correlation between the ground, vegetation, and air over a defined urbanized area over a diurnal cycle (24 to 48 h) [46]. The usefulness of ENVI-met in the study of public spaces has been confirmed in a number of scientific publications [47], and successive versions of the software are being extended with new functions. Currently, the software is one of the leading tools in the study of urban green and blue infrastructures (GBI) in the context of climate change. The study uses both reference models of example spaces, created on the basis of statistical models [48], as well as real, concrete spaces [45,49]. The two approaches complement each other, and allow design measures aimed at improving microclimatic conditions and perceived user comfort to be optimized.

The ENVI-met 5.0.2 software was used to carry out the climate simulations for this study. This is currently the most up-to-date software that allows comprehensive urban climate surveys to be carried out with an accuracy of one square meter. Numerous studies prove that it is possible to use this software to study the climate of urban areas [22,50]. Using this software, an area of 240 × 240 m, or 5.76 hectares, was modelled, containing the public space at Jesienna Street in Lublin (51°14′03.6″ N 22°35′51.4″ E), together with buildings in the vicinity, greenery, and traffic routes. The modelled area includes the study area, which is a square. All elements were given appropriate parameters reflecting the real ones, such as the height of the buildings, the material they are made of, and the species in the case of trees and shrubs.

2.2. Temperature Test for a Selected Space

The study was conducted for the warmest day in Lublin, falling on 26 July, when the average temperature is 19.9 °C. The maximum temperature is 24 °C and the minimum temperature is 15.4 °C. The humidity averages 69%. These data were obtained from the Climate Data website and climate table for the city of Lublin from 1991 to 2021 [51].

This day is considered the warmest day of the year on average based on the last decade. Occasionally, it can be cloudy and stormy on this day, causing the temperature to be higher on another day. Heat waves also occur on other days, including June and August. However, in order for there to be one date in all simulations, 26 July was adopted. Data for 2010 as the warmest day was adopted from a publication on strong thermal waves for Lublin when the minimum temperature during a heat wave in July in Lublin was 12.1 °C and the maximum temperature was 32.9 °C [52]. These data were adopted for the T1 simulation.

The data for 2020 were extracted from the weather archive publicly available on the website. During the warmest day, the minimum temperature was 13.0 °C and the maximum temperature was 33.2 °C [53–55]. Such data were adopted for the T2 simulation. For the T3 simulation and others, the temperatures were set to be 1.5 °C higher [56] to simulate an increase in temperature for the minimum temperature of 14.5 °C and the maximum temperature of 34.7 °C. The minimum and maximum temperatures for each day were assumed for each simulation in the ENVI-met software.

Simulations were performed for a whole day (24 h). The start of the simulation was at 5 am For each simulation carried out, the minimum and maximum temperatures on a 24-h scale were determined using the simple forcing method. From the files generated by the software to compare the results, the hours of 8 a.m. and 4 p.m. were selected as the most significant due to the fact that the highest traffic volumes in public space occur during these hours.

The meteorological station closest to the study area is the station of the UMCS Department of Meteorology and Climatology, MPWiK Hajdow (φ = 51°15′39″ N, λ = 22°37′43″ E), and Lublin Plac Litewski 3 (φ = 51°15′ N, λ = 22°34′ E). They are located in built-up areas. Since 1973, the Institute of Meteorology and Water Management has been collecting data from the Lublin-Radawiec Station, which is several kilometers away from the city (code 495, geographical coordinates: φ = 51°13′ N, λ = 22°24′ E). However, as early as 1950, Guminski noted that climate and temperature are different in urbanized and non-urbanized areas [57]. This is due to the inflow of cool air from the Bystrzyca Valley, and the difference in the ground, which heats up considerably in the city center [58]. Historical data from stations located in the center of the city of Lublin, managed by the UMCS, and data stored by the National Research Institute were used for the study. Information on air temperature, relative humidity, and wind speed and direction, together with atmospheric pressure for the month of July, was used to conduct the study.

2.3. Analysis of Existing Buildings

The study area is bounded by buildings of varying dimensions. On the north-east side, there is a multi-family building, 160 m long and 12 storeys high. On the west side, there are single-family two-story buildings, and on the south side, the area is bounded by a multi-family, 5-story building and a one-storey service pavilion. The multi-family buildings are made of prefabricated reinforced concrete, insulated with polystyrene foam, covered with thin-coat plaster, with roofs covered with asphalt felt. The above information is summarized in Table 1.

Table 1. Characteristics of buildings in the study area.

Buildings in the Area				
Nr	**Location**	**Building Area [m^2]**	**Floors**	**Material**
1	10 Zimowa Street	1650	12	walls: reinforced concrete prefabricated + styrofoam + plaster; roof: roofing felt
2	7 Jesienna Street	650	5	walls: reinforced concrete prefabricated + styrofoam + plaster; roof: roofing felt
3	3,5 Jesienna Street	192	3	walls: walls: brick + styrofoam + plaster; roof: steel sheet tile
4	12 Zimowa Street	80	2	walls: brick + styrofoam + plaster; roof: steel sheet tile
5	3 Zimowa Street	464	5	walls: reinforced concrete prefabricated + styrofoam + plaster; roof: roofing felt
6	14 Zimowa Street	115	1	walls: brick + styrofoam + plaster; roof: steel sheet tile
7	14 Jesienna Street	80	2	walls: brick + styrofoam + plaster; roof: steel sheet tile
8	42 Pogodna Street	1362	1	walls: reinforced concrete prefabricated + styrofoam + plaster; roof: roofing felt

There is a public playing field in the southern part of the study area, and a playground square located in the northern part. The whole area is generally accessible for walking and passive recreation. The survey area with the designation of the numbers listed in Table 1 is shown in Figure 2a. The same area modeled in ENVI-met is shown in Figure 2b.

2.4. Land Balance

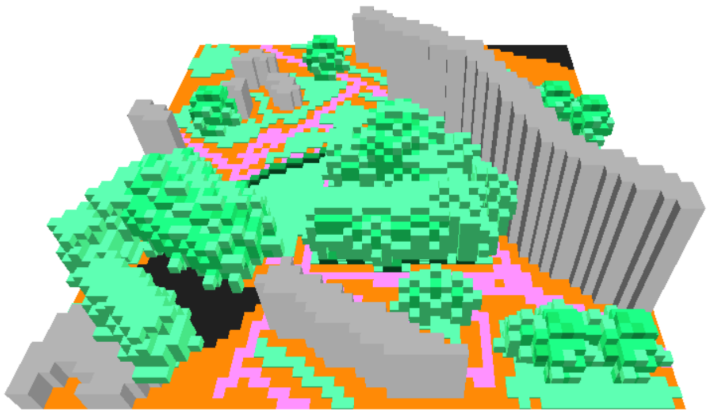
The square in question has surfaces commonly found in Polish cities in residential public spaces. The pavements are made of grey or red small-sized concrete cubes, or light-grey 30 × 30 paving slabs; the road surfaces and car parks are made of asphalt; the playing field has an asphalt surface; and the playground is largely sanded. The lawns in the study area are mown regularly and are less than 10 cm high. A site balance was recalculated for the surveyed area. The biologically active area represents 59% of the study area, whereas the paved area represents 30% and the buildings represent 10% (Table 2).

2.5. Green Analysis

An essential element for proper simulations was the analysis of the existing greenery stock. A greenery inventory of the study area was carried out on 20 June 2022 (Table 3). Twenty-six tree and shrub species were identified, for a total of 362. The number of shrubs forming hedges, such as barberry and ligustrum, were calculated by dividing the length of the existing hedge by the measured width of the average shrub, which were approximately 1.0 m and 1.2 m, respectively.

The largest percentage of greenery is occupied by shrubs formed into hedges. New plantings consist of shrubs and deciduous trees planted in 2017. These include *Prunus virginiana*, *Prunus cerasifera*, *Dasiphora fruticosa*, and *Buddleja davidii*. The central square, measuring 0.34 hectares, was mostly used for new plantings. The largest number has been planted with cherry trees, which reach a growth height of up to around 7 metres. They are located 2–3 m apart, in a regular arrangement without communication links or the introduction of new features. *Prunus cerasifera* were planted in the northern part of the square. Twelve of the twenty-nine *Prunus cerasifera* did not take root. The remaining inventoried trees and shrubs were planted in previous years. Of the trees, a large percentage are occupied by maples, of the shrubs by jasmine. The species selection found in the study area is common/typical for settlements in Lublin dating from the second half of the 20th century.

(**a**)



(**b**)

Figure 2. (**a**) Survey area with numbers, (**b**) view of the ENVI-met survey model area.

Table 2. Summary of pavements in the study area.

Land Balance		**%**
Material	**[m^2]**	
The area of the reaserch	31.195	100
Built-up area	3268	10
Bilogically active area	18.488	59
Paved area, including:	9439.2	30
Area covered with paving stone	2230.9	7
Area covered with large format paving slabs—30 × 30	502.7	2
Area paved by asphalt	6705.6	21

Table 3. Table listing identified tree and shrub species and their percentage share in relation to each other.

	Existing Planting (Trees and Shrubs)			
Lp	**TYPE of Tree**	**Number of Units**	**Percentage of Species**	**Properties (2022)**
1.	*Prunus cerasifera*	29	4.23%	Regular spread 2 × 3 m, height 3 m, crown diameter approx. 2 m
2.	*Prunus virginiana*	69	10.06%	Regular spread 2 × 3 m, height 3 m, crown diameter approx. 2 m
3.	*Aesculus hippocastanum*	3	0.44%	Trees approx. 50 years old, solitary tree height 20 m, crown diameter approx. 9 m, others respectively: 12 m/8 m
4.	*Betula pendula*	2	0.29%	Trees approx. 30 years old, solitaries 15 m high, crown diameter approx. 6 m
5.	*Physocarpus opulifolius*	15	2.19%	Krzewy o wys. 1.5 m dojrzałe
6.	*Acer pseudoplatanus*	24	3.50%	Trees approx. 40 years old, group, tree height 10 m, crown diameter approx. 8–12 m
7.	*Tilia cordata Mill.*	8	1.17%	Trees approx. 50 years old, height 12 m, crown diameter approx. 9 m
8.	*Salix × sepulcralis 'Chrysocoma'*	1	0.15%	Trees approx. 30 years old, 12 m high, crown diameter approx. 6 m
9.	*Catalpa bignonioides*	2	0.29%	Trees approx. 10 years old, solitaries 7 m high, crown diameter approx. 6 m
10.	*Robinia pseudoacacia* L.	7	1.02%	Trees approx. 50 years old, height 12 m, crown diameter approx. 8 m
11.	*Picea abies*	8	1.17%	Trees approx. 40 years old, tree height 12 m
12.	*Larix decidua*	6	0.87%	Trees approx. 40 years old, tree height 10 m
13.	*Platanus acerifolia*	1	0.15%	Trees approx. 10 years old, tree height 5 m
14.	*Carpinus betulus*	1	0.15%	Trees approx. 40 years old, 10 m high, crown diameter approx. 6 m
15.	*Morus alba* L.	2	0.29%	Trees approx. 50 years old, 10 m high, crown diameter approx. 6 m
16.	*Fraxinus excelsior* L.	5	0.73%	Trees approx. 50 years old, 15 m high, crown diameter approx. 8 m
17.	*Thuja occidentalis*	5	0.73%	singles
18.	*Parthenocissus quinquefolia*	1	0.15%	planting by pergolas with benches
19.	*Parthenocissus quinquefolia*	1	0.15%	planting by pergolas with benches
20.	*Quercus robur 'Fastigiata'*	1	0.15%	Trees approx. 20 years old, 8 m high, crown diameter approx. 3 m
21.	*Philadelphus coronarius*	24	3.50%	planting along the building
22.	*Buddleja davidii*	50	7.29%	group planting
23.	*Rugosa rose*	1	0.15%	group planting
24.	*Dasiphora fruticosa*	96	14%	group planting
25.	*Berberis thunbergii*	106	15%	formed hedge, 0.8 m high
26.	*Ligustrum vulgaris*	218	32%	formed hedge, 1.3 m high

2.6. Simulation Procedure

Seven simulations (T1, T2, T3, T3′, T3′′, T4, and T5) were executed to determine the microclimatic conditions in the selected space and the perceived temperature comfort for the years, 2010, 2020, and 2050. By comparing the results, an attempt was also made to check to what extent the plantings carried out after 2017 contributed to the betterment of the climactic conditions in the space in question. Three simulations: T1, T2, and T3, refer to the existing condition and the expected results from the existing solutions, whereas the T3′ and T3′′ trials refer to the design proposal resulting from the analyses of the T2 and T3 simulations. Simulation T4 was conducted to see what the temperature would be in

2050 in the square without trees, and simulation T5 was conducted to compare what the temperature would be for 2050 if there were no trees in the whole area.

The first stage of the study analyzed the existing condition for 2010, i.e., when there were no new plantings in the study area (T1). The next stage concerned the analysis for 2020, after the existing plantings had been made (T2). The results were then collated to see to what extent the new plantings contributed to improving the climactic conditions in the space in question. In the next step, a simulation was performed for 2050, when the optimistic scenario presented by the IPCC (Intergovernmental Panel on Climate Change) predicted that the Earth's global temperature would increase by 1.5 °C, whereas by 2100, the global average temperature would increase by 3.2 °C [56]. The next step is to try to introduce more plantings in the form of broadleaf trees, native species familiar with urban conditions, assuming their planting in 2022 and them reaching the dimensions of a mature tree (about 12 m). For the purposes of the study, a planting of 15 common *Acer platanoides* was adopted as a species complement to the existing stand in the study area. They were located in the southern part of the square, so as to provide as much shade as possible, in an area where such plantings would be feasible. As a final step, a T3″ simulation was also carried out for 2050, with the addition of 5 common *Acer platanoides*, re-densifying the plantings proposed in the T3′ simulation. It was also decided to add a small retention basin, in the form of a rain garden, in the central part of the square, and to rehabilitate the existing car parks in the north-western part of the study area. The data obtained in the T3″ simulation were compared with the T3′ data to see to what extent new planting and the introduction of water into the study area could improve the thermal comfort of the space in 2050 (Table 4, Figure 3).

Table 4. Summary of simulation conditions.

Simulation Number	Summary of Parameters	
	Year	Site Condition
T1	2010	lack of planting in the square
T2	2020	new planting in the form of trees and shrubs, new pavements
T3	2050	no new planting after 2020, existing young decorative trees reach maximum sizes
T3′	2050	new planting in 2022, simulation with new planting of broadleaf trees on the south side of the square
T3″	2050	simulation with new planting of broadleaf trees on the south side of the square, rain garden in the central part of the square, recultivation of the existing car park and addition of trees in its place
T4	2050	without greenery in the central part of the square (grass only)
T5	2050	no greenery in the whole area (grass only)

2.7. *Human Thermal Comfort Check*

Using the ENVI-met model output files, the BIO-met post-processing tool was used to calculate human thermal comfort indices. Human heat stress studies were compiled for each period, T1, T2, T3′, and T3″. Four cases of the average user of the area were studied, including sensitive, prone-to groups. Particularly, sensitive groups to extreme weather conditions include chronically ill people, children under 5 years of age, and people over 65 years of age. Extreme weather conditions are disruptive and also pose threat to people with disabilities and limited mobility, the homeless, as well as the general population of the city. In Lublin, currently 28% of the population is over 60 years of age, and children under 6 years of age account for nearly 5.5% of the population [35]. It can be estimated that age-sensitive social groups make up about one third of the city's population. Due to the ageing of the population, the number of older people will increase. The study estate, like most estates built in the second half of the 20th century, is predominantly inhabited by older people, so it can be estimated that the problem will substantially increase. Cases H1a and H1b were, therefore, developed for a man and a woman aged 35, and for H2a and H2b, for a man and a woman aged 75 (Table 5).

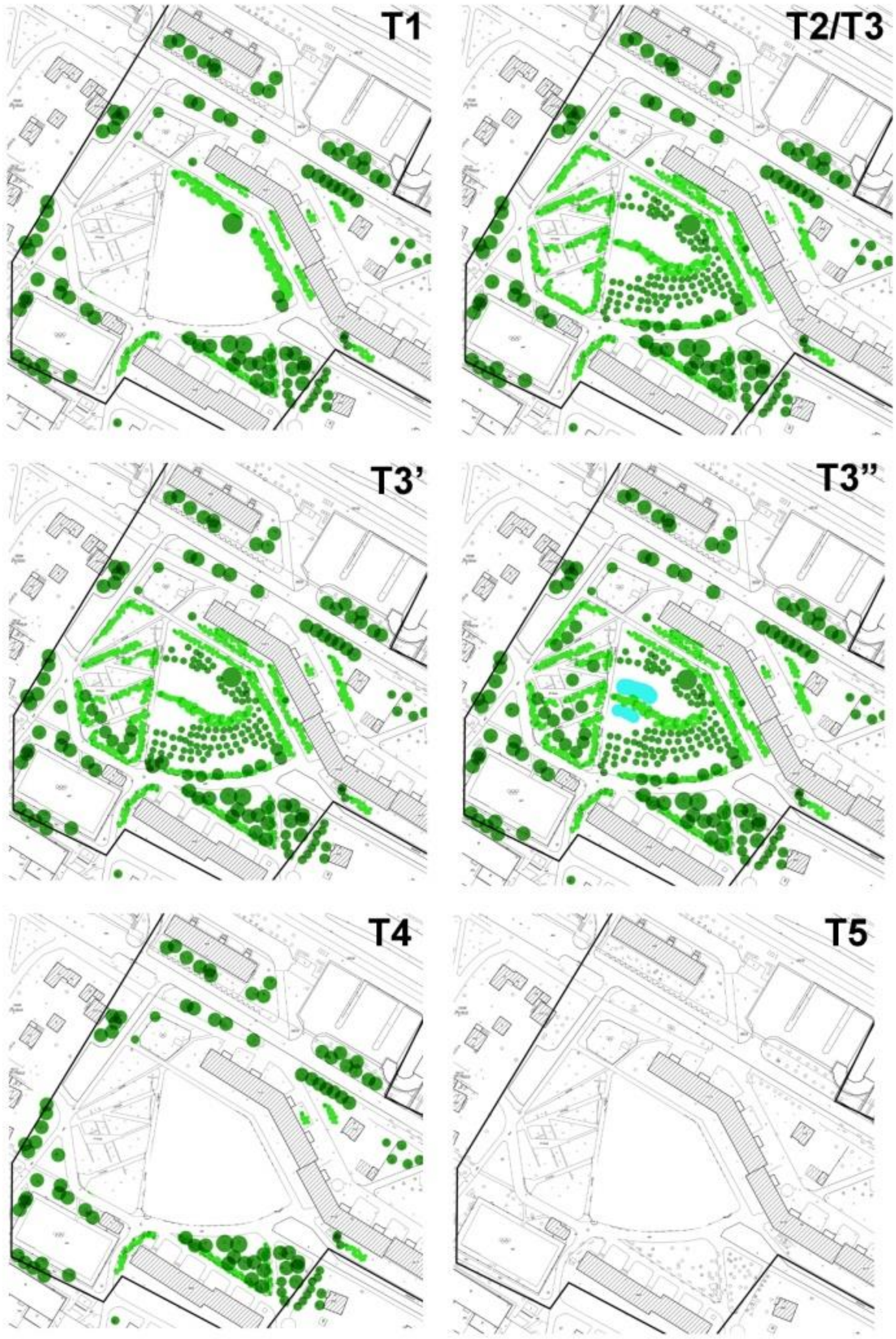


Figure 3. Graphical overview of simulations.

Table 5. Table summarizing the human parameters used in simulations.

Simulation Number	Summary of Human Parameters			
	Gender	Age [L]	Height [m]	Weight [kg]
H1a	man	35	1.75	75
H1b	woman	35	1.65	65
H2a	man	75	1.75	75
H2b	woman	75	1.65	65

Human thermal comfort was assessed using the Physiologically Equivalent Temperature (PET) index, which is the air temperature in a defined indoor environment that is unaffected by wind and solar radiation [59]. An assessment of thermal comfort was developed in 1999 by Matzarakis et al. [60]. According to the PET index, a temperature between 18.1–23.0 °C is defined as comfortable, with no perceived thermal stress. A temperature between 23.1–29.0 °C is defined as slightly warm, and the grade of physiological stress is slight. A temperature between 29.1–35.0 °C is described as warm, and the grade of physiological stress is moderate heat stress. A temperature between 35.1–41.0 °C is described as hot, and the grade of physiological stress is strong heat stress. At temperatures above 41.0 °C, a person feels very hot and reaches an extreme heat of the grade physiological stress.

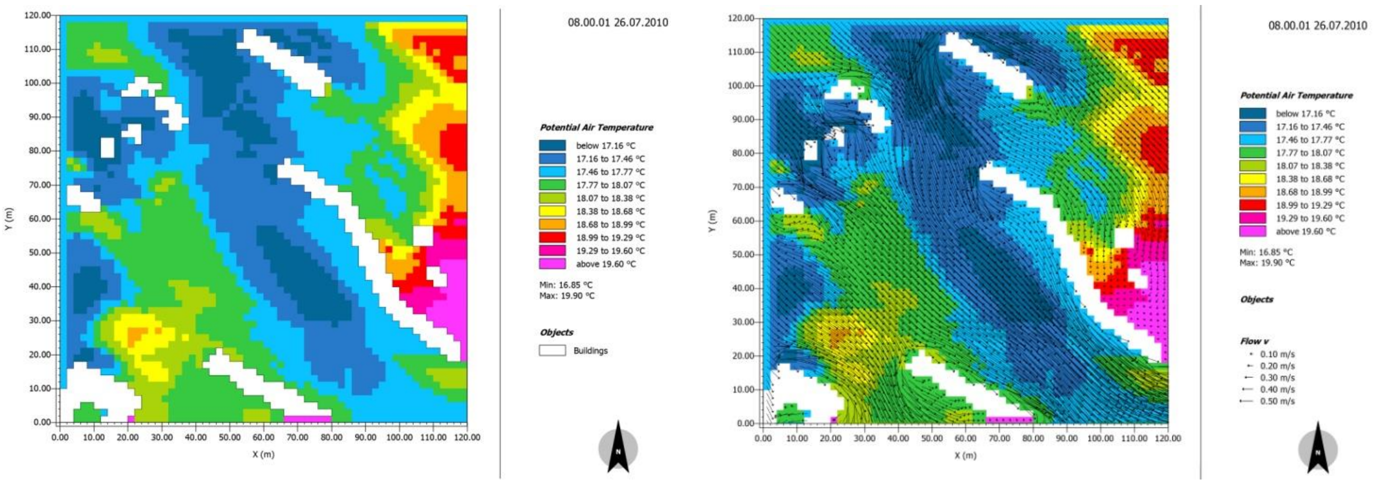
The thermal comfort analysis was carried out in the morning (8:00) and afternoon (4:00), when there is the most traffic on the streets and in the square. It should be mentioned that no users were encountered in the surveyed square during the midday seasons, when the air temperature is above 30.00 °C.

3. Results

3.1. Results of Climate Simulations for Individual Years

3.1.1. Simulation T1

In the T1 scenario, for 2010 at 8:00 a.m., the temperature ranged from 16.85 °C to 19.90 °C. Buildings restricted the wind flow, as can be seen particularly in the central part of the study area. The lowest temperature of 17.16 °C is only found where jasmine trees and taller trees, such as *Aesculus hippocastanum* L. and *Tilia cordata Mill.* trees, were growing. A slightly higher temperature occurs on the south side of the longest building, and is between 17.16 °C and 17.46 °C. A higher temperature, in the range between 18.38 °C and 19.90 °C, is found in the part that is largely covered by paved surfaces; this is the large surface car park and Wincentego Witosa Avenue (Figure 4). The lowest temperature values were observed at 5 a.m., and the highest at 4 p.m.



(**a**) (**b**)

Figure 4. (**a**) T1 simulation for 8 a.m., 26 July 2010; (**b**) T1 simulation for 8 a.m., 26 July 2010 with flow (image generated by ENVI-met).

3.1.2. Simulation T2

In the T2 scenario, the temperature ranged from 18.17 °C to 21.03 °C. The overall temperature is higher, but in the graphical representation of the simulation, it can be seen that the lower temperature occupies a larger area of the central part of the square than in the T1 simulation (Figure 5). Undoubtedly, the new plantings carried out in 2017 have contributed to this. Air movement is blocked, especially by the buildings located in the area, and more greenery contributes to the improved microclimatic conditions.

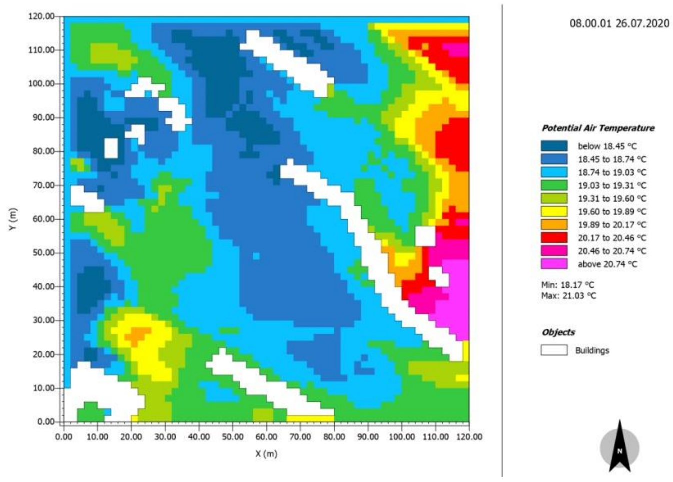


Figure 5. T2 simulation for 8 a.m., 26 July 2020 (image generated by ENVI-met).

3.1.3. Simulation T3

Simulation T3 performed for 8:00 a.m., 26 July 2050. In this simulation, no changes or transformations were made to the space. Vegetation was left unchanged, as in 2020, which means that the ornamental trees have changed little in size. A temperature 1.00 °C higher than in 2020 was introduced. The result is a lowest temperature of 19.17 °C and a highest temperature reaching 21.94 °C (Figure 6).

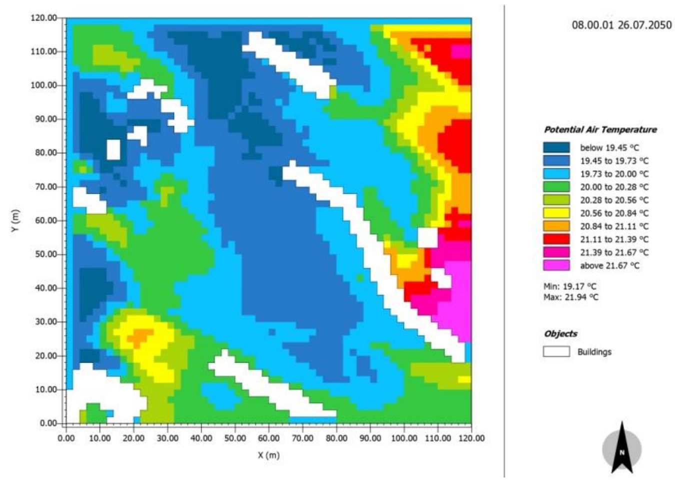


Figure 6. T3 simulation for 8 a.m., 26 July 2020 (image generated by ENVI-met).

3.1.4. T3′ Simulation

Another simulation was carried out for 2050, with the aim of checking whether the new planting proposed by the authors of the article could contribute to improving the microclimatic conditions in the study area. After an inventory and analysis of the vegetation present in the study area, it was decided to introduce 15 *Acer pseudoplatanus*. These are characterized by their broad habit of the leaves, which allows them to absorb more solar energy and produce a large amount of oxygen during photosynthesis. After analyzing a T3 simulation showing the heat flux, they were added on the south and north-west sides of the square. For 8 a.m., the temperature varied from 19.14 °C to 21.95 °C (Figure 7). Relative to the T3 simulation, the lowest temperature dropped by 0.03 °C. The graphical result of the simulation clearly shows that, due to the new plantings, the lower temperature covers a much larger area than was the case in the previous speculations.

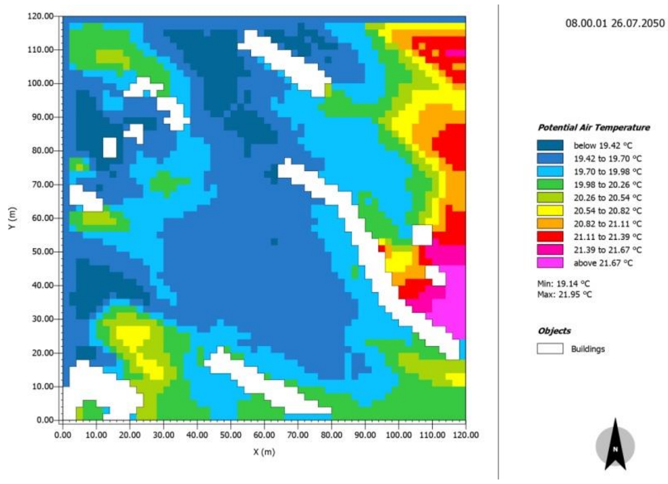


Figure 7. T3′ simulation for 8:00 a.m., 26 July 2020 (image generated by ENVI-met).

3.1.5. T3″ Simulation

The last simulation was carried out for 2050, after planting an additional 10 *Acer pseudoplatanus* on the north-west side of the site, removing part of the paved area intended for a car park designed to accommodate around 20 cars, and adding a small water reservoir in the central part of the site. In the T3″ spec, the morning temperature changed by 0.1 °C, which may be due to minor programming errors. It can, therefore, be considered unchanged from the T3′ temperature speculation. A noticeable change is the light blue hue in the center of the study space (temperature between 17.71 °C and 19.99 °C) (Figure 8), which is in the vicinity of the water body. It can be concluded that it has affected the overall temperature distribution in this space.

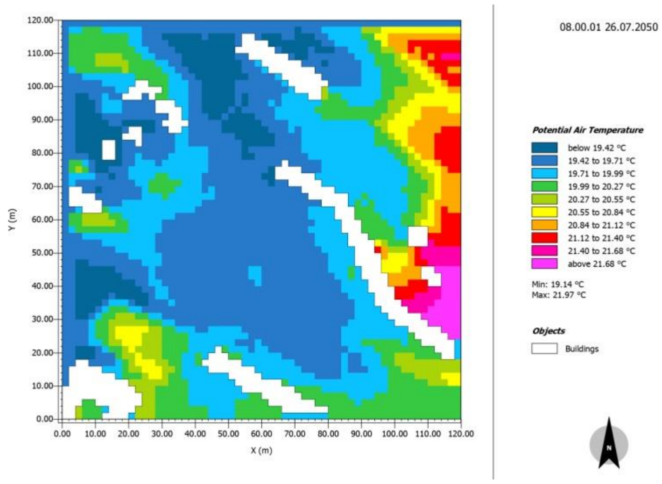


Figure 8. T3″ simulation for 8:00 a.m., 26 July 2020 (image generated by ENVI-met).

3.1.6. Comparison of Table Results

The simulation results obtained were compared with each other for the hours, 8:00 a.m. and 4:00 p.m. These hours were selected because this is when there is the most traffic, pedestrians, and users on the square. A heat stress simulation, presented in the next section, was also performed for these hours. In the table below (Figure 9), it can clearly be seen that at 4:00 p.m., the T3, T3′, and T3″ simulations differ minimally from each other. In the T2 simulation at 4:00 p.m., small areas with temperatures between 27.28 °C and 28.44 °C are visible. The temperature shifts with the wind direction, which has been entered the same for each simulation from the north-west, which is typical for the summer period in Lublin. In each simulation, you can see the heat flux passing in the same direction: through the central part of the study area.

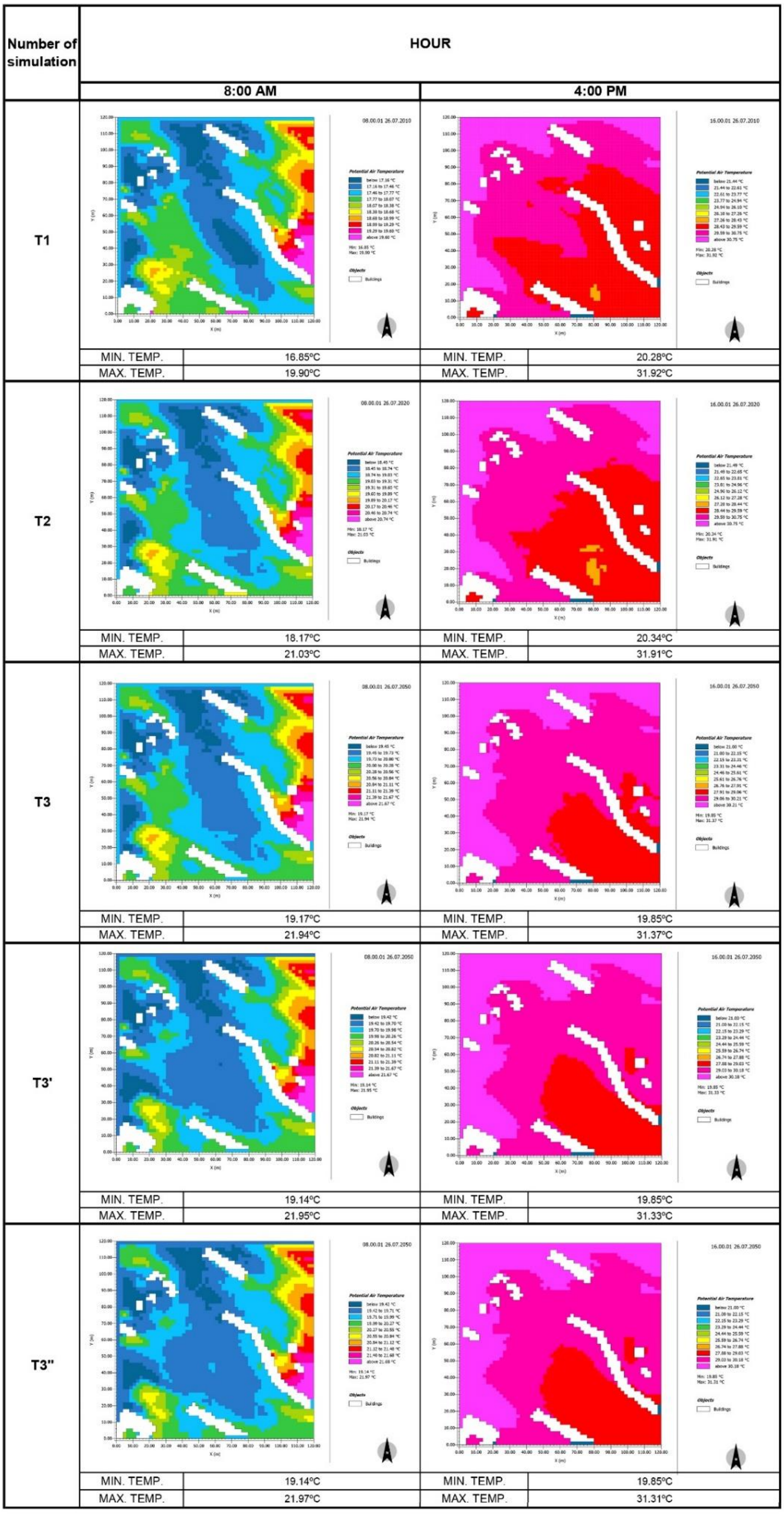


Figure 9. Summary of performed simulations.

From the simulations, it can be seen that the maximum temperatures were not achieved for the temperatures assumed at the beginning according to the archive data. It is most likely due to the use of the simple forcing method. Research indicates that the use of this method is associated with inaccuracies in the temperature obtained when compared to the real data, and those obtained from weather stations for a particular day. Using this method, the software forces the climate parameters to behave over a 24-h period over the entire study area, disregarding the specific data collection site [61,62]. Temperature is slightly different than the archive data because the "Simple Forcing" option for temperature allows hourly average values of these parameters to be taken into account. This method uses a constant average wind speed and direction for the entire simulation time [63]. The simple forcing method takes generalized output data. Although the ENVI-met model did not give accurate results with respect to the real situation, and did not achieve a maximum temperature, it is effective in estimating the thermal variability caused by the general conditions in the area [64].

For 8 a.m., when the square is in shadow due to the rising sun, the simulations also show cooler air masses concentrated around the trees there. Compared to the 2017 plantings (98 trees: *Prunus cerasifera* and *Prunus virginiana*, and 146 shrubs: *Dasiphora fruticosa* and *Buddleja davidii*), the planting of 25 *Acer pseudoplatanus* was surprisingly more effective. These represent just over 10% of the greenery planted in 2017. Therefore, it can be concluded that it is more effective to plant a few trees with a wide trunk and crown, such as maples, than dozens of smaller trees with a much smaller crown.

Often, the felling of large trees is compensated for by new plantings without proper consideration for the appropriate species. Sometimes, these new plantings are trees with a small trunk diameter and a maximum height of 10 m. Such a tree will not create the same microclimatic conditions as a noble tree, which grows taller and has a wide crown. The choice of tree species must be sensible and cause no disturbance to the residents.

3.1.7. Space without Greenery

Two simulations, T4 and T5, with the same climate data, were performed for 2050. For simulation T4, only the central part of the square was cleared of greenery. For simulation T5, the tree canopy was removed completely for the entire study area. In both simulations, the paved areas and the biologically active area were left unchanged. The results were compared with the T3 simulation, i.e., with the existing planting for 2050, to see the difference (Figure 10).

Table 3 and T4, an increase in the minimum temperature of 0.09 °C was observed at 8:00 a.m. From the graphical representation, the difference in the range of the minimum temperature can be observed. In the T3 simulation, it covered a much larger area. When the plants were removed from the yard in simulation T4, the temperature distribution decreased, and, thus, the minimum temperature increased. This is caused by the wind direction and the shadow cast by the building. In simulation T5, there is clearly a larger area covered by green and yellow colors, which indicates an increase in temperature across the area. The maximum temperature between these simulations decreased by 0.18 °C. Between simulation T3 and T5, the temperature difference is 0.36 °C. This is how much the temperature would increase if all the trees in the study area were removed. For all simulations, the minimum temperature at 4:00 in the afternoon was the same. The maximum temperature increased by 0.05 °C for simulation T4 and 0.74 °C for simulation T5. The results clearly show that greenery contributes to lowering the local temperature.

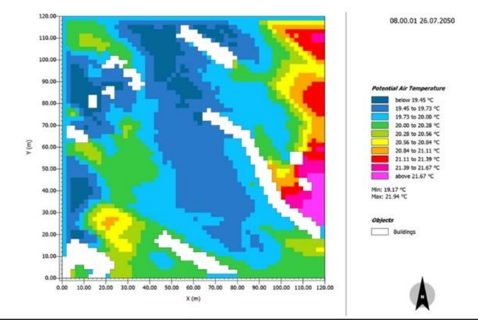
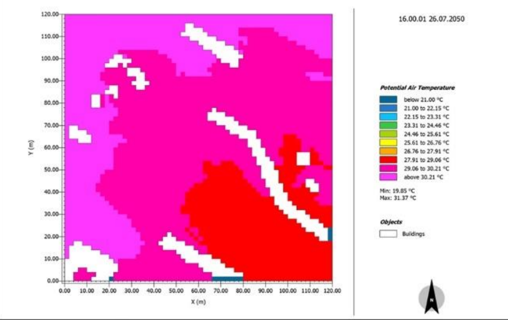
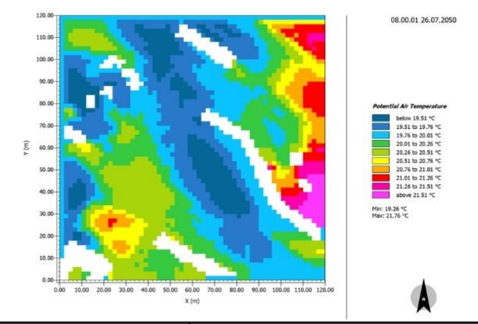
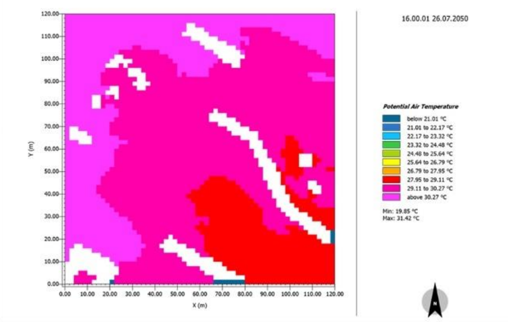
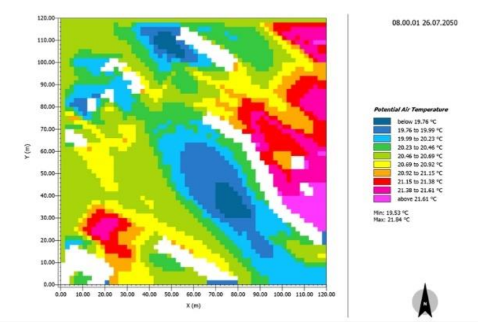
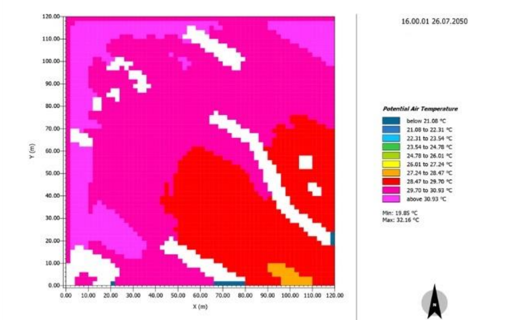
Number of simulation	Hour			
	8:00 AM		4:00 PM	
T3				
	MIN. TEMP.	19.17°C	MIN. TEMP.	19.85°C
	MAX. TEMP.	21.94°C	MAX. TEMP.	31.37°C
T4				
	MIN. TEMP.	19.26°C	MIN. TEMP.	19.85°C
	MAX. TEMP.	21.76°C	MAX. TEMP.	31.42°C
T5				
	MIN. TEMP.	19.53°C	MIN. TEMP.	19.85°C
	MAX. TEMP.	21.84°C	MAX. TEMP.	32.16°C

Figure 10. Comparison of T3 simulations with T4 and T5.

3.2. Analysis of Human Thermal Comfort

3.2.1. Results for Individual Groups at 8:00 a.m.

In simulation H1a-T1, i.e., for a male aged 35 years, at 8:00 a.m., the perceived minimum temperature was 13.40 °C, giving the effect of slight cold stress according to the Grade of Physiological Stress PET [65]. The maximum reached 36.96 °C, giving the sensation of strong heat stress. In the central part of the square, the prevailing temperature was between 15.76 °C and 25.18 °C, giving a temperature sensation between slightly cool, comfortable, and slightly warm. In the T3′ and T3′ simulations, it is clear to see to what extent the plantings proposed by the authors have improved the microclimatic conditions for the entire space. The more favorable zone for staying was significantly increased, and the lowest temperature dropped by 0.20 °C compared to the T3 simulation. In the center of the square, i.e., where the new plantings are taking place, it is between 15.40 °C and 17.64 °C. This results in slight cold stress. On the north-east side of the square, a person will not experience heat stress. It can be concluded that, despite an increase in average air temperature by 2050, small interventions, such as the planting of new wide-crowned trees, will have a very positive effect on the local microclimate and people's desire to stay in this space. In the rest of the area, located outside the surveyed square, humans can experience temperatures between 36.96 °C and 38.17 °C. These are areas left to direct sunlight exposure. For each of the simulations, the human will experience strong heat stress at these temperatures.

For simulation H1b, that is, for a woman aged 35, the results appeared to be very similar. The difference is the T1 simulation with a minimum temperature of 13.20 °C at 8:00 a.m. This is 0.20 °C less than for the man at the same time, but the PET sensation is the same (slight cold stress). The maximum temperatures at the same hour differ by a maximum of 0.03 °C, which has no significant effect on the sensation of thermal comfort. Therefore, it can be concluded that temperature sensation is slightly influenced by gender, whereas it is predominantly influenced by age.

For the H2a simulation, i.e., for a man aged 75, who is in the sensitive group studied, at 8:00 a.m., the sensible minimum temperature for T1 was 13.94 °C. This is 0.54 °C higher than for the man aged 35, but the sensation according to the PET index is the same, i.e., slightly cool. The sensation of the highest temperature at 8:00 a.m. is 0.56 °C higher compared to H1a. For the T2 simulation, it is 0.40 °C higher, and for the T3 simulation, it is another 0.40 °C higher. From the data obtained, it can be seen that a man aged 75 years experiences a temperature 0.40 °C higher than a man aged 35 years. The result between simulation T3 and T3′ and T3″ is interesting. In the former, the minimum perceived temperature was 16.00 °C, whereas in the latter, it decreased to 15.80 °C. As a result, it gives a feeling of slight cold stress. It can be concluded that the new plantings have succeeded in lowering the perceived temperature for the elderly person by 0.20 °C. The addition of a small water reservoir and the removal of several square meters of the car park in simulation T3′ had no significant effect on lowering the perceived temperature. The results for the maximum temperatures at 8:00 are very similar to the previous ones. The conclusion is that a man aged 75 years will perceive a temperature 0.40 °C higher than a man aged 35 years.

For the H2b-T1 simulation, i.e., for a woman aged 75, the temperature at 8:00 a.m. was 13.80 °C, i.e., 0.60 °C higher than for a 35-year-old woman. For the T2 simulation, the difference was 0.20 °C, whereas for the T3 simulation, it was 0.23 °C. In the T3′ and T3′ simulations, the minimum temperature was 15.60 °C, whereas it was 15.40 °C for the 35-year-old woman. This results in a difference of 0.20 °C. From the above data, it can be concluded that a 75-year-old woman experiences a temperature 0.20 °C higher than a 35-year-old woman (Figure 11).

3.2.2. Results for Group at 4:00 p.m.

At the warmest time of the day, i.e., at 4:00 p.m., in the H1a simulation for a 35-year-old man, the minimum temperature was 26 °C, giving a slight heat stress effect according to the Grade of Physiological Stress PET. The maximum was 46.57 °C, making the heat sensation an extreme heat stress level. After planting at T2 spec, the minimum temperature was 25.80 °C, a decrease of 0.20 °C. The graphical representation shows the heat flux moving in the central part of the square. The dark blue color corresponds to the lowest temperature, whereas yellow, orange, red, and pink correspond to higher temperatures. For the other simulations, the minimum temperature was 24.00 °C, giving a slightly warm feeling. In the T3′ and T3″ specs, it is noticeable that in the central part of the square, the temperature between 24.00 °C and 25.94 °C is in a much larger area than in the T2 spec.

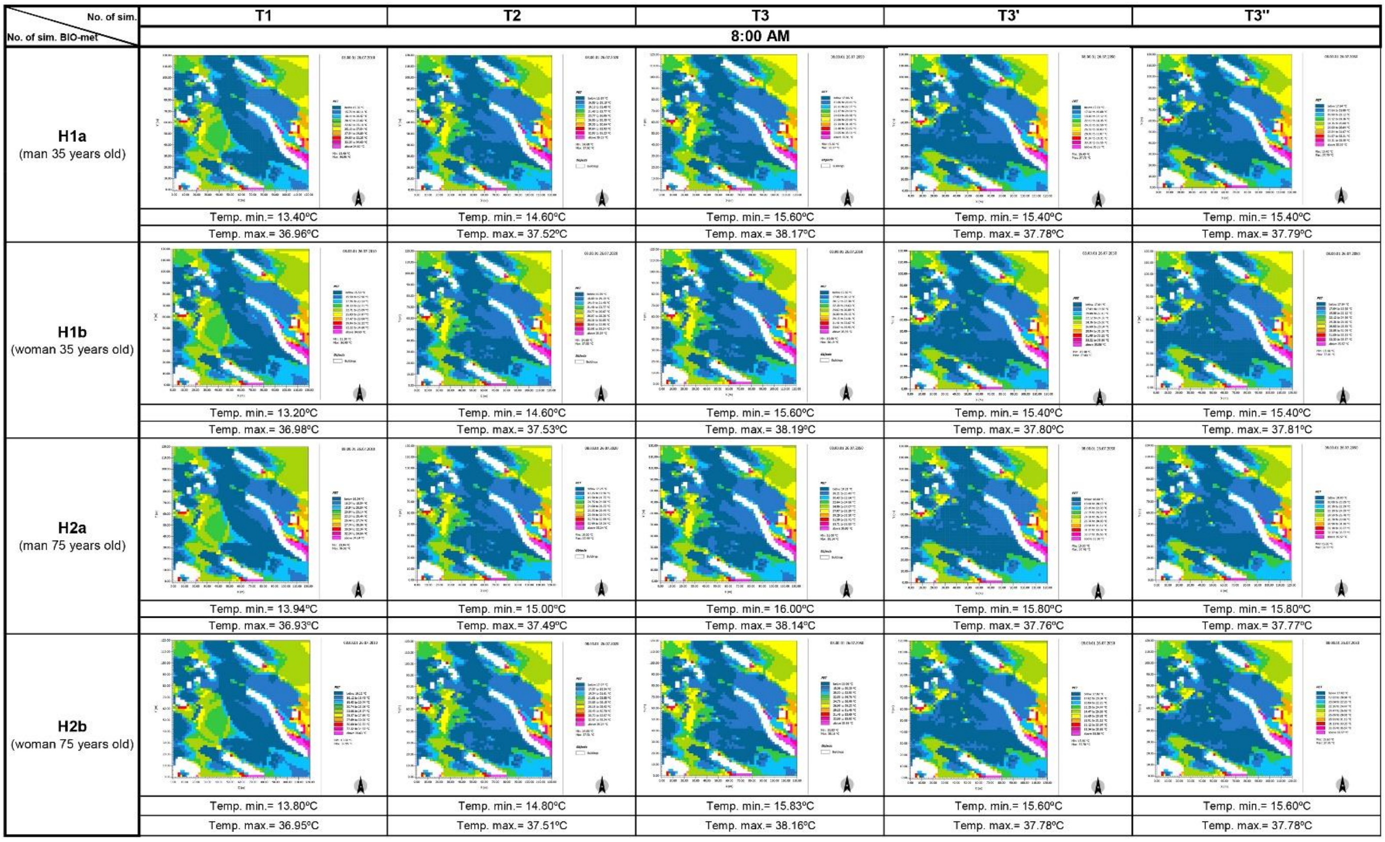


Figure 11. Summary of simulations for each group at 8:00 a.m.

For H2a, i.e., a man aged 75 years, the minimum temperature in the T1 and T2 specs is the same as for a man aged 35 years, giving the effect of slight heat stress. The maximum temperature differs by 0.01 °C, which is within the simulation errors. In the T3, T3′, and T3″ specs, the minimum temperature is 24.40 °C, which is 0.40 °C higher than for a man aged 35. This is confirmed by the study performed for 8:00 a.m. If a man aged 75 were in the same part of the square as a man aged 35, their temperature sensations would be 0.40 °C different, making their levels of heat stress possibly different.

For simulation H1b, i.e., for a woman aged 35, in simulation T2, the temperature is 25.60 °C. For the same simulation for a woman aged 75 (H2b), the minimum temperature is 25.80 °C. This gives a difference of 0.20 °C. In the T3, T3′, and T3″ specs, the temperature is 24.00 °C for H1b and 24.20 °C for H2b. The above tests confirm the data obtained at 8:00 am for the same age groups. A woman aged 75 years feels a temperature 0.20 °C higher than a woman aged 35 years (Figure 12).

3.2.3. Results for the Area without Greenery at 8:00 a.m. and 4:00 p.m.

From the comparison of the BIO-met simulations for men and women aged 35 and 75, it can be seen that the temperature increases with each simulation (Figure 13). For a man and a woman aged 35, the minimum temperature between simulation T3 and T4 increased by 0.20 °C.

Between simulation T4 and T5, it increased by as much as 1.00 °C. For a man and a woman aged 75, the temperature at 8:00 a.m. slightly differs, but the maximum temperature remains the same. A 75-year-old woman experiences a temperature 0.17 °C lower than a man of the same age for the T3 simulation. For the T4 simulation, the difference is 0.20 °C. In the T5 simulation, the temperature remains the same for the woman and the man. The maximum temperatures differ by 0.02 °C, reaching a maximum of 38.15 °C in the T4 simulation, and 40.95 for the T5 simulation. In the T5 simulation, it can be clearly seen that the paved surfaces have a different temperature than the biological surfaces. One can see the difference between an asphalt surface and a cobblestone surface. In the simulations, they settled on yellow and light green temperatures, respectively.

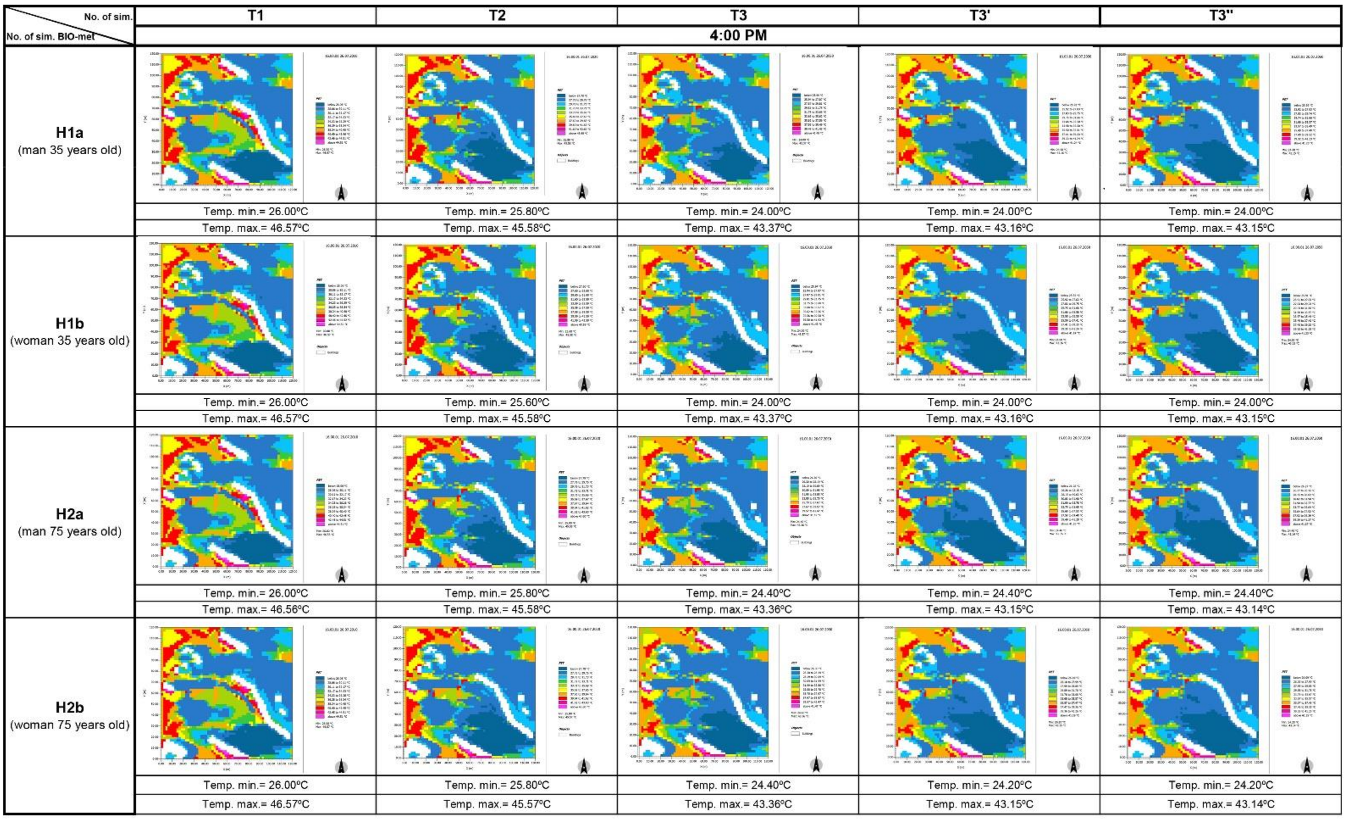


Figure 12. Summary of simulations for each group at 4:00 p.m.

At 4:00 p.m., the temperature was higher for each simulation. Between T3 and T4, the minimum temperature for males and females increased by 0.40 °C. For the T5 simulation, it was an increase of 1.00 °C. The maximum temperature was very similarly distributed, reaching a temperature for the T4 simulation of 44.22 °C, and for the T5 simulation, of 51.55 °C. For a man and a woman aged 75 years, the perceived temperature differed. For the T4 simulation at 4:00 p.m., the man felt a minimum temperature 0.20 °C higher than the woman of the same age, at 24.80 °C. The maximum temperature was the same at 44.21 °C. For the T5 simulation, i.e., without vegetation throughout the study area, the minimum temperature was the same for all age groups, at 25.40 °C. The maximum temperature was 51.63 °C for the woman aged 75 and 51.55 °C for the man. The minimum and maximum temperatures increased compared to previous simulations with vegetation. In the T5 simulation for 4:00 p.m., the temperature distribution for the paved surfaces is clearly visible. The predominant color is yellow for surfaces paved with asphalt. The central part of the square shows green for the biologically active surface, and light green where the surface is covered with paving stones. The perceptible temperature on the T5 simulation in yellow (asphalt) at 4 p.m. is between 38.42 °C and 41.03 °C, whereas in light green (pavement), it is between 35.82 °C and 38.42 °C.

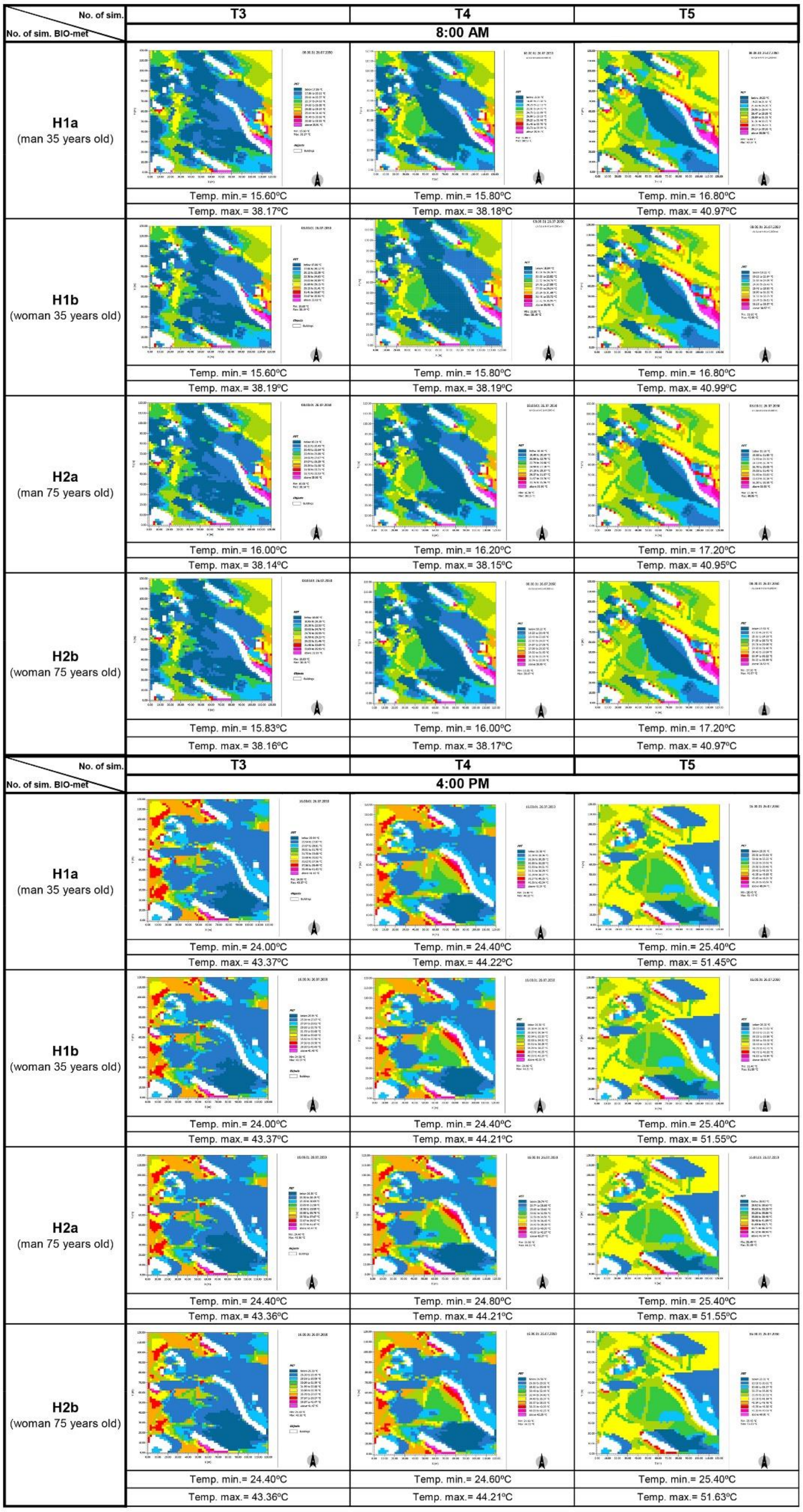


Figure 13. Comparison of BIO-met speculation for 8:00 a.m. and 4:00 p.m. T3 with T4 (no vegetation in the square) and T5 (no vegetation in the whole area).

4. Discussion

The increasing proportion of elderly people with longer periods of social and workplace activity means that the perception of thermal comfort of this social group is of research interest in many centers, and should be pursued for public open spaces [66].

From the analysis carried out in the discussed study area, it appears that the elderly (compared to those aged 35 regardless of gender, according to the PET index) experience slightly higher temperature ratios. A study by Baquero Larriva and Higueras García (2019) shows that older people are less sensitive to thermal changes, and their comfort zone is wider than that of adults [67]. A decreased sensitivity to temperature changes in the elderly is a well-described phenomenon in terms of a health and physiological issue [60]. This phenomenon can ultimately lead to health disadvantages. Designing public spaces for the comfort of older people should combine spatial temporal distribution with functional needs [68]. In the analyzed public space, the new compensatory plantings will have little impact on the advancement of thermal comfort due to inadequate, random species selection (small ornamental trees) and location, as confirmed in the article, "Effects of tree seasonal characteristics on thermal-visual perception and thermal comfort" [69].

It is important to create public green spaces that accommodate for the various needs of people in cities. The Commission Staff Working Document, Guidance on a Strategic Framework for Further Supporting the Deployment of EU-Level Green and Blue Infrastructure [70], aims at halting and reversing the accelerating loss of biodiversity and ecosystem services. Urban greening can be promoted at a strategic level so that, while greening in public spaces, the city can reap the benefits. In cities, attractive green infrastructure promotes social cohesion and reduces social inequalities. Cities should be designed to be inclusive for residents, and safe and sustainable. Cities have the opportunity to create modern spaces with blue infrastructure, brimming with cycle paths. Even appropriately designed climate spaces can improve the cities' microclimate, air quality, and, more importantly, the quality of life of the inhabitants and resilience to natural disasters [70].

Trees take a long time to grow, and predicted periods of drought mean that it is of crucial importance to act now when it comes to carrying out new planting. Street trees are particularly important, but their development, viability, and maintenance in the street course is difficult, and involves a variety of technical solutions to maintain tree health and limit damage to the pavement [71]. At the same time, as shown by the results of studies carried out under similar climatic conditions (Czech Republic), the effect of vegetation on lowering the temperature of an urban heat island may, in some cases, be barely noticeable or even the opposite. Adding trees on the account of building and impervious surface fractions (trees + 30%) in the compact midrise development might even increase air temperature [72].

More than 20 years ago, US researchers estimated that around 20% of cooling demand in the US could be avoided by implementing large-scale heat island mitigation measures [73]. A number of studies are now looking at the impact of pedestrian-level urban greenery and urban geometry in improving urban thermal comfort [74].

Temperature differences between central, densely built-up urban zones and suburbs in temperate climates can be up to 10 °C [72], and their impact on human well-being and health is particularly noticeable for vulnerable groups such as the sick, children, or the elderly. Thus, adaptation strategies should be integrated into urban ecosystems to improve the quality of life and public health [75]. The very issue of the perception of comfort by the user of public spaces is very complex and may relate not only to a temporary feeling of temperature, but also individual socio-demographic characteristics and long-term psychological factors [59]. It is important to consider how long one has lived in a given place, as well as the functional offer of the space, its attractions, and the level of aesthetics. Adaptation to climate change is also intrinsically linked to the localness of architectural and urban forms and traditions, and each climatic region requires a distinct urban form and configuration, which can contribute to making a city or neighborhood cooler or warmer, depending on the needs of their users [76,77].

The public spaces accompanying multi-family developments in the form of detached blocks of flats are, in many respects, different from the public spaces accompanying quarterly developments. The spatial structure of Polish cities is dominated by estates built in the second half of the 20th century, constructed in accordance with modernist ideas of situating detached blocks of flats in communal greenery. Both individual buildings and their surroundings are currently undergoing revitalization and modernization processes. Proper recognition of the issue of the directions of climate change can help to shape these areas appropriately, so that the design decisions whose effects will be visible in a few or several years' time are optimal [78].

The successful management of public space in a residential environment is made possible by a holistic approach encompassing not only perceptible temperature aspects, but also functional and compositional issues. The proposed planting has the greatest impact not only on the temperature distribution, but also on the aesthetics of the place and its public perception.

5. Conclusions

In the context of climate change, a demographically-structured vegetation model, which addresses multiple vegetation parameters and takes into account the life cycle of the plant, seems to be the most appropriate [79]. In the case of the square under study, compensatory plantings of over 100 trees will make little contribution to the improvement of thermal comfort due to insufficient, improper selection, and the location of plant species (small ornamental trees). The study shows that it is more effective to plant fifteen trees that grow to a height of several tens of meters than 100 trees that grow to a few meters. The larger ones have substantially greater prospects for better reduction of the local temperature and the recovery of the microclimate. A significant outcome of the study should reveal where the plantings should be distributed in order to achieve the best result and create a public space where people are more likely to spend time. The best result was achieved with plantings on the south-west side, as these create shade in the afternoon. Previous plantings were located on the south-east side of the square, which did not have a satisfactory effect. The research shows the great usefulness of the ENVI-met application in green space design in order to receive the most satisfactory results in future years. Reliable data on future climate change scenarios can be essential for architects and urban planners to properly design public spaces in cities from a climate perspective.

The survey also showed that vegetation has a significant impact on the temperature of the space and people's thermal comfort (PET). An analysis of the simulation results showed that people aged 75 years old feel higher temperatures than those aged 35 (men 0.40 °C, women 0.20 °C). According to the simulations, the perceptible temperature for people in the entire study area without vegetation would increase by as much as 1.00 °C. It can be noticed in the simulations that a higher temperature is achieved by a surface paved with asphalt than with paving stones.

The results proved how simulations can be used for any public space development in future years, considering different age groups. Demographic data reveal that the ageing of the population is increasing, and the proportion of people 65+ in the population is rising. In future, it is this largest social group that will be most affected by high temperatures. The most important challenge faced by modern cities such as Lublin is the adaptation to changing climatic conditions. The effectiveness of the adjustment to climate change depends on the local government institutions, which need to know what measures need to be taken in order to be successful once implemented, as well as economical. Collaboration between scientists and local government using appropriate tools, such as ENVI-met, can be extremely fruitful.

Author Contributions: Conceptualization, N.P. and B.K.; Data curation, N.P., B.K. and M.K.; Formal analysis, N.P. and M.K.; Investigation, N.P. and B.K.; Methodology, B.K. and M.K.; Project administration, N.P.; Resources, N.P., B.K. and M.K.; Software, M.K.; Supervision, N.P.; Visualization, N.P. and M.K.; Writing—original draft, N.P., B.K. and M.K.; Writing—review and editing, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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