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Original Research

Effects of Different Types of Residential Block Greenery in Summer Conditions in Areas of Moderate Continental Climate on Thermal Comfort

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Abstract

The research is based on result analysis of simulations of reference and prediction models of residential blocks in ENVI-met software. The reference model was designed according to the constructed residential block located in Nis. Predictive block models were considered, such as models with: green roofs, green facades, with increased ground greenery and a combined model with application of all above types of greenery. Another point that was considered was the median air temperatures and PET at 1.5 m height during the day across the entire residential block and selected measuring points within the block. The median air temperature of prediction models varies from the median temperature of the reference model by +0.11ºC to -0.23ºC at block level, while the PET of prediction models varies at block level from +0.91ºC to -4.2ºC, which leads to a change in category of thermal sensation and physiological stress. Due to different features of measuring points, the air temperature values and PET also differ. The largest difference in air temperature in relation to the reference model occurs at measuring point P2 in model with increased floor greenery and measures -0.91°C, while the largest difference in PET in relation to reference model occurs at measuring point P4 in model implementing all types of greenery and measures -18.45°C.

Keywords: ambient air temperature, PET, urban block thermal comfort, green roof, greenery

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Introduction

Urban areas make up only 3% of the entire area of our planet, and more than 50% of the population lives there [1]. According to the United Nations data, during 2020, 57% of the population lived in cities, and it is predicted that by 2050 this percentage will reach 68% [2]. As an effect of urbanization, the cities' structures begin to expand, which leads to an increase in the ambient air temperature in the city in relation to the surrounding rural area – the urban heat island effect (UHI) [3]. The cause of the heat island effect is not unique but represents a combination of several factors that can be divided into 5 parts: reduction of evaporation [4], increase in heat accumulation from solar radiation [5], increase in net radiation of accumulated heat [6], convection reduction [7] and an increase in heat of anthropogenic origin [8]. The heat island effect is particularly striking during the hot summer nights when there is emission of solar energy absorbed by the structure materials in the city [9]. It is estimated that average global temperature will increase between 1.4 and 5.8ºC from 1990 to 2010 [10].

Ways to reduce the heat island effect are different, ranging from those that define the features of objects and their relationship within the block [11] analyzing the most suitable type for planning new settlements, to those that perform interventions in the existing city structure to achieve the desired effect. According to Nuruzzaman [12] the most important strategies for reducing the heat island effect include: the application of materials with high albedo for covering buildings and paving, increasing water surfaces, increasing greening surfaces, increasing shading by applying trees with large treetops, as well as applying green roof surfaces on buildings. One of the most effective ways to increase the thermal comfort of an area and to reduce the heat island effect is to increase the green area surfaces on a location [13]. The increase can be achieved through the implementation of floor greenery, green facades, green roofs and their combination.

Ca et al states that in Japan, the cooling effect of the park area is 0.6 km^2 discovered 1 km away from the park in the wind direction where a 1.5ºC lower air temperature was measured [14]. Jamei and associates point out that areas with green areas are 1ºC-7ºC cooler than the surrounding areas and that this phenomenon is called "park cold island" [15]. In their research, Blanco et al determined that greenery on the facade reduces the facade temperature by 5ºC-7ºC compared to a facade without greenery. [16]. Peng et al. analyzed different forms of urban blocks and the cooling effect using green facades. The maximum cooling effect of -0.59ºC at the ground floor level was determined in high-density building blocks in buildings that are 48 m high. [17]. Mutani et al. analyzed the possibility of implementing green roofs on buildings in selected neighborhoods of the city of Turin in Italy. They determined that increasing greenery to 15% through roof greening would reduce ground temperature by 2.7ºC, save about 14 GWh of energy per year and reduce CO_2 emissions for 2840 tons per year [18]. Herath et al conducted research on the example of the city of Colombo, Sri Lanka. They analyzed different models according to the percentage of greenery on the roofs of buildings and proved that 100% green roof surface coverage affects the reduction of air temperature by 1.79ºC [19].

Apart from the air temperature, the PET thermal comfort index stands out as a significant factor in the evaluation of thermal conditions in a certain area. Gomez et al. [20] have shown that the application of large paving surfaces in the design of open urban spaces leads to large thermal reflections and increased thermal stress. The research used the PET index to describe changes in biometeorological parameters, which showed that the PET thermal comfort index can be applied to find adequate solutions for open space design.

Knaus et al. [21] investigated the use of the PET index to assess thermal comfort when applying intensive green roofs in a residential block in Berlin. The research covered the basic model of a residential block and an alternative with an intensive green roof. The paper concludes that the application of an intensive green roof does not lead to significant changes in air temperature and PET index at ground floor level due to the distance between the ground floor and the roof. On the other hand, the application of green roofs had an impact on reducing thermal stress at the roof level, so roof spaces were characterized as spaces of qualitatively increased thermal comfort.

The paper analyzes the urban block intended for collective housing with open spaces between residential buildings and recreation of residents of that block, as well as visitors. The analysis is based on a comparison of the microclimatic conditions of the block reference model and prediction models that differ from the reference model in the use of different green solutions. The paper discusses the location of the urban block model in Nis, a city located in the southeastern part of the Republic of Serbia.

Material and Methods

Description of the Location and Area Climate

The climate of the city of Nis is moderately continental with harsh winters. Frost is a common occurrence during the winter, spring lasts a short time, and the summer period is characterized by warm weather with high humidity. The average annual temperature is 11.4ºC. The warmest months of the year are July with an average temperature of 24.32ºC and August with an average temperature of 24.41ºC while the coldest month is January with a temperature of +0.6ºC.

Meteorological parameters for the city of Nis, used in the paper, were obtained by forming a meteorological file in the Meteonorm software package. The data used in the paper presents a typical summer day at the considered location. The obtained data were created based on measured values of solar radiation in the period from 1991-2010, and air temperatures in the period from 2000-2009.

Description of the Urban Block Model

The ENVI-met [22] v 4.4.5 software package was used to form the analysis model.

The reference model (R-MODEL) of the urban block is defined according to the parameters of the built urban block. The block is separated from the main road via a buffer zone to the northeast, it has residential buildings organized in lamellas with floors P+3+Pk. The height of the buildings, the distance from one another, the layout of the surfaces on the ground floor as well as greenery in actual state are arranged in the same way in the basic model. Compared to the entire area, the buildings occupy 15.07% of the base area, greenery occupies 39.62% of the area and different types of paving 45.29% of the base area.

There is no traffic network for motor vehicles inside the block, but the organization of the block is defined by footpaths between which are green areas covered by low vegetation. Tall greenery is mostly present in the buffer zone, while there are a small number of tall trees inside the block. Tall greenery trees which can be found include: Tilia Cordata, Pinus, Acer Pseudoplatanus, Betula Pendula, Platanus x Acerifolia.

The model was created based on a rectangular shape measuring 148x114 cells. The size of the horizontal cells along the x and y axis is 2 m, while the height of the cells along the z axis is 3 m, which means that the entire area is 296 m with 228 m at the base, while the height measures 84m. Furthermore, 3 boundary fields (nesting grids) are envisaged at the edges of the area in order to avoid problems when calculating the impact, and due to the proximity of the built structure to the boundary it covers [23, 24].

In addition to the reference model, 4 more different MODELS were created with proposed solutions for the implementation of green areas: MODEL I with extensive green roofs, MODEL II with green facades, MODEL III with additional bushy greenery and trees, MODEL IV - Green model. MODEL variants (MODEL I, MODEL II, MODEL III and MODEL IV) were formed with the aim to research the effect of the implementation of different types of greenery on the thermal comfort of area benefactors of the observed urban residential block.

Table 1 shows the area of greenery for each of the formed models, as well as their share in the total area of buildings in the researched area of the urban block.

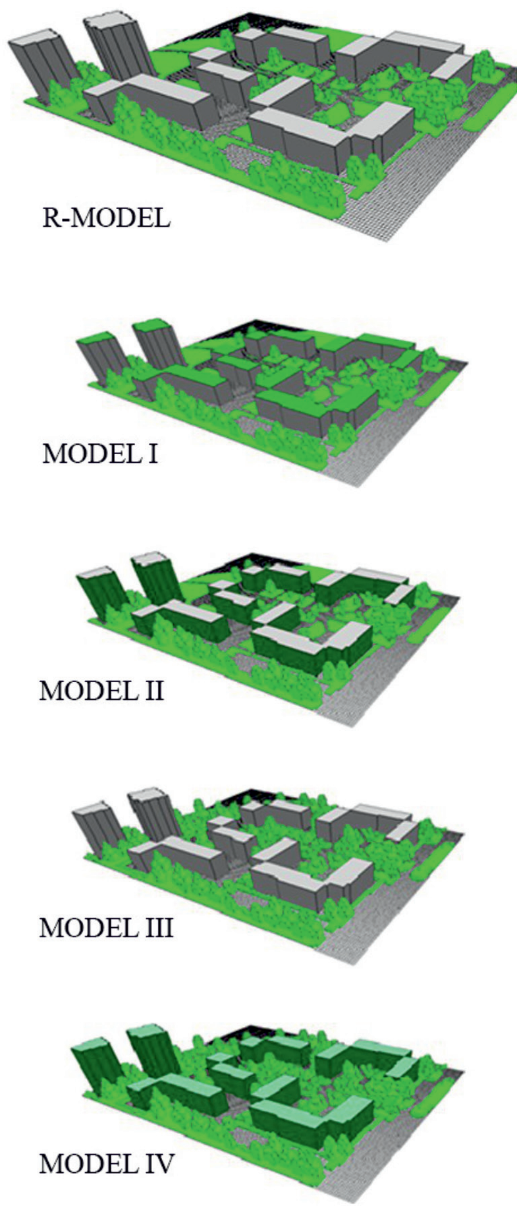

Fig. 1. Reference model and models with proposed solutions for the implementation of greenery of the urban block created in ENVI-met.

Determining the Microclimatic Conditions Using the PET index

Thermal comfort indices are used to determine thermal comfort in the outdoor and indoor environment. The paper used the thermal comfort index PET to determine the microclimatic conditions of the outdoor, using the software package ENVI-met. PET represents the air temperature at which in a typically closed environment (without the influence of solar radiation and wind) the temperature of the human body is balanced with the internal body temperature and skin temperature in external conditions [25]. The PET thermal comfort index is a significant factor in the evaluation of thermal conditions at a micro location.

Table 2 given by Matzarakis was used to show the PET categories [26].

Table 1. The share of green areas of the researched models in relation to the gross area of the URBAN block.

Model	Total area covered with greenery	Increasing the area of greenery	Percentage of greenery	Increase in the total percentage of greenery	Total surface
R-MODEL	26 743 m^2	Ref. MODEL	26.35%	Ref MODEL	101,464 m^2
MODEL I	36 919 m^2	11 338 m^2	36.38%	+38%	
MODEL II	60 719 m^2	33 946 m^2	59.84%	+127%	
MODEL III	26 743 m^2	-	26.35%	+0%	
MODEL IV	70 895 m^2	44 152 m^2	69.87%	+165%	

Table 2. PET - categorization of thermal sensation and physiological stress depending on the temperature.

PET	Thermal sensation	Assessment of physiological stress
<4	Very cold	Extreme cold
4-8	Cold	Severe cold
8-13	Chilly	Moderate cold
13-18	Partly cold	Mild cold
18-23	Pleasant	No thermal stress
23-29	Partly warm	Mild heat
29-35	Warm	Moderate heat
35-41	Hot	Strong heat
>41	Very hot	Extreme heat

Parameters Used in Simulations in ENVI-met

After designing the urban residential block model, the basic simulation parameters were defined in the ENVI-met software package. August 1 was chosen as the starting day of the simulation, and the duration of the simulation was limited to 48 hours. The duration of simulations in research varies from 12h to several days [24, 26-29]. The recommended duration of the simulation is a minimum of 24 hours for the system to achieve balance, i.e., to avoid errors in the output parameters due to the unreliable behavior of objects on the site. [24]. When processing the research results, the data obtained on the second day of the simulation were used, i.e., from hour 24 to hour 48.

Table 3 shows the defined input parameters for the simulation.

When analyzing the PET index in ENVI-met software package, the input parameters used were selected in accordance with the standard ISO 7730 and correspond to the standard North American and European person given in Table 4. [30].

Table 3. Basic model data and simulation input parameters.

Beginning and duration of simulations			
Start Date		August 1, 2019	
Starting Time		07:00:00	
Simulation duration		48h	
Input meteorological data			
Initial air temperature		18.1ºC	
min (August 2, 2019 04:00 h)		11.6ºC	
Max (August 1, 2019 15:00 h)		33.8ºC	
Initial humidity		65%	
min (August 1, 2019 15:00 h)		21%	
max (August 2, 2019 02:00 h)		90%	
Wind speed at a height of 10 m		0.6 m/sec	
Wind direction		268º	
Rotation of the model relative to the north		45.08º	
Geographic data for Nis			
Altitude		195m	
Latitude		43.33	
Longitude		21.89	
Number and size of cells and boundary conditions			
Number of cells along the x axis	148	dx	2
Number of cells along the y axis	114	dy	2
Number of cells along the z axis	28	dz	3
Number of boundary cells		3	
Boundary cell land		Loamy soil	

Results and Discussion

The results of the simulations are given through the display of air temperature (AT) values and thermal comfort index (PET). Fig. 2 shows a graphical representation of the AMBIENT air temperature for all considered models of the urban block (MODEL, MODEL I, MODEL II, MODEL III, MODEL IV) for the following time frames: In the morning at 05:00 when

Table 4. Human input parameters for PET index calculation.

Personal human parameters	
Body parameters	
Gender	Male
Age of person (years)	35
Weight (kg)	75
Height (m)	1.75
Surface Area (DuBois-Area)	1.91m^2
Clothing parameters	
Static Clothing Insulation (clo)	0.90
Persons metabolism	
Total Metabolic rate (W)	164.49 (= 86.21 W/m^2)
Total Metabolic rate (met)	1.48

the air temperature is at its lowest during the day, at 09:00 which represents the morning temperature when area users are most active, at 15:00 when the highest temperature during the day is measured for the observed time interval and at 21:00 immediately after sunset.

Graphic representation refers to different time periods during the day.

Tables 5 and 6 show values of median air temperature and median PET per hour during the day. The median parameter value can be used when there is potential unreliability and errors in measuring extreme value of the parameter.

Places were selected within the researched location which showed a comparative view of air temperature and PET throughout the day. The position of selected places is given in Fig. 3.

P1 to P4 are positioned within the block on footpaths, while P5 relies on an access traffic network. Table 6 provides an overview of features of selected sites and their insulation, average wind speed and wind exposure.

P1 and P4 are open to the southwest so they are insolated until late afternoon, while the surrounding buildings cast shadows in the morning.

P3 was chosen as the opposite of P1, the open space is located on the northeast side so there is direct solar radiation in the morning. P2 is in a slightly better position in terms of insolation than P3 and is located on an open corridor that stretches northwest to southeast. In the late afternoon, P2 is in the shade. P5 is the most open in terms of natural air circulation while in terms of insolation it is most similar to P2, and sunny almost all day.

Table 7 shows the air temperature of all considered models in relation to the selected places P1-P5, and Table 8 shows the PET values for the considered places.

Based on the obtained results, their analysis was performed through AT and PET analysis for the considered models of the urban block with different greenery scenarios (MODEL I, MODEL II, MODEL III, MODEL IV) in relation to the R-MODEL.

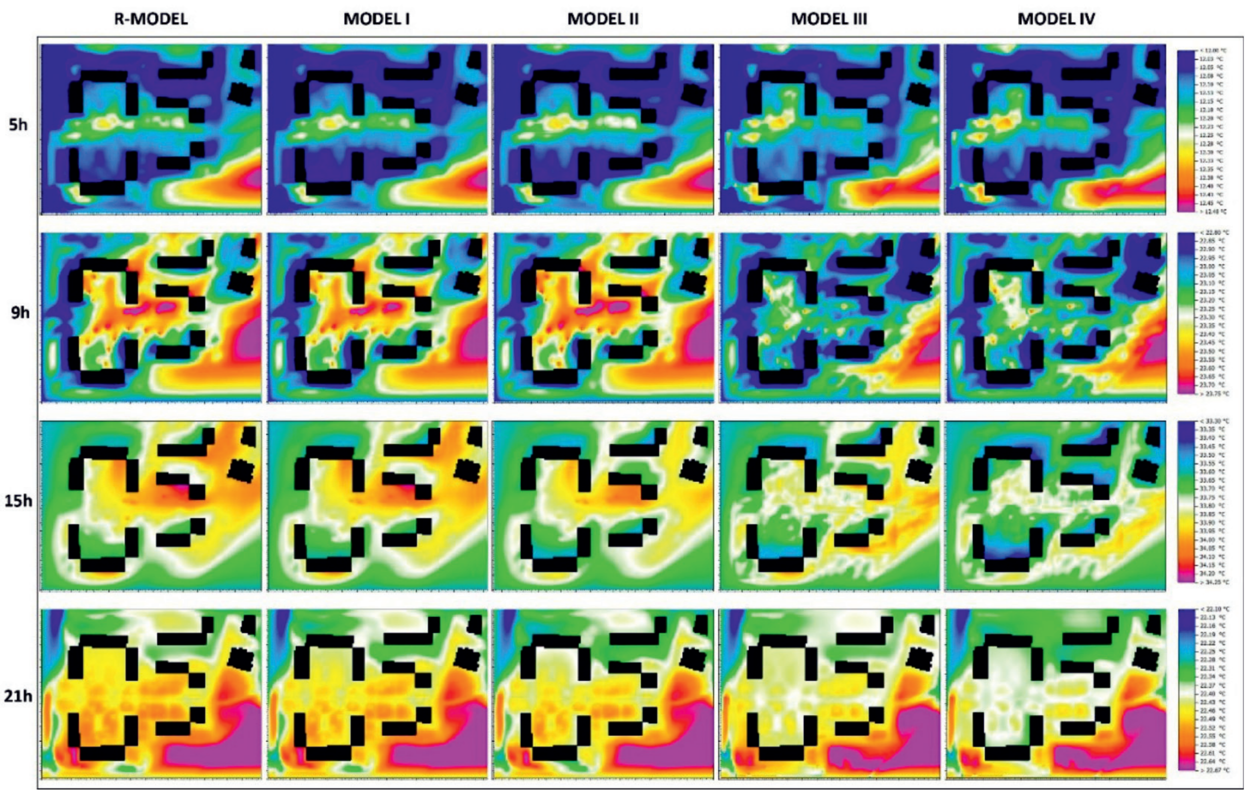

Fig. 2. Air temperature in URBAN BLOCKS at different time intervals during the day.

Table 5. Hourly value of median temperature and median PET of the observed models (R, I, II, III, IV) during the day.

	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Median air temperature																								
R-MODEL	16.29	15.15	13.41	12.78	12.2	12.11	14	16.5	20.04	23.26	26.68	29.12	31.52	32.99	33.39	33.8	33.14	31.73	29.63	27.03	24.7	22.47	20.37	18.12
MODEL I	16.27	15.14	13.37	12.75	12.18	12.09	14	16.51	20.05	23.24	26.66	29.09	31.48	32.97	33.38	33.78	33.13	31.72	29.63	27.02	24.69	22.46	20.35	18.09
MODEL II	16.25	15.14	13.35	12.74	12.19	12.1	14.04	16.55	20.13	23.28	26.68	29.09	31.48	32.94	33.37	33.75	33.12	31.71	29.6	26.99	24.68	22.44	20.32	18.08
MODEL III	16.39	15.17	13.42	12.81	12.22	12.11	14.05	16.49	19.92	23.09	26.48	28.95	31.35	32.91	33.41	33.75	33.13	31.7	29.55	26.98	24.66	22.43	20.37	18.2
MODEL IV	16.32	15.16	13.34	12.77	12.2	12.09	14.11	16.55	20.03	23.11	26.49	28.91	31.29	32.85	33.37	33.7	33.1	31.67	29.5	26.93	24.63	22.4	20.32	18.14
Median PET																								
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	12.23	11.48	10.34	8.69	7.66	8.46	11.57	22.03	26.68	28.6	35.21	35.37	39.11	41	40.39	42	38.75	35.72	28.2	21.82	19.2	17.2	15.47	13.51
MODEL I	12.22	11.47	10.32	8.68	7.66	8.46	11.58	22.06	26.8	28.6	35.19	35.35	39.09	41	40.39	42	38.74	35.72	28.2	21.8	19.2	17.2	15.45	13.5
MODEL II	12.32	11.55	10.4	8.78	7.76	8.56	11.91	22.22	26.89	28.6	35.29	35.41	39.14	41	40.33	42	38.72	35.7	28	21.8	19.2	17.26	15.6	13.63
MODEL III	12.75	11.89	10.74	9.28	8.3	9.34	11.77	18.46	25.05	27.8	34.52	34.58	38.42	40.54	40.17	41.2	37.58	31.61	27.02	22.22	19.6	17.83	15.98	14.42
MODEL IV	12.81	11.93	10.77	9.32	8.35	9.41	12	18.72	25.46	27.85	34.63	34.62	38.45	40.49	40.13	41.2	37.53	31.52	27	22.24	19.8	17.94	16.09	14.53

Table 6. Overview of measuring points and their exposure to direct sunlight and wind.

Point	Communication Type	Insolation period during the day (24h)	Average wind speed (m/s)	Wind exposure
P1	Pedestrian	10h-16h	0.573	Small
P2	Pedestrian	6h-16h	1.31	Large
P3	Pedestrian	7h-11h	0.532	Small
P4	Pedestrian	11h-18h	0.629	Medium
P5	Car	6h-15h	2.095	Large

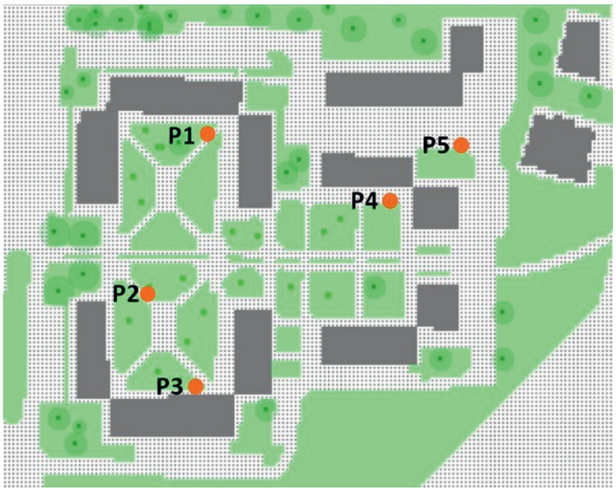

Fig. 3. Position of selected places (P1, P2, P3, P4, P5).

A comparative analysis was performed of median air temperatures/PET per hour during the day for each model and place (P1, P2, P3, P4, P5).

Comparative analysis of the reference model with prediction models (MODEL I, MODEL II, MODEL III, MODEL IV) shows there is a decrease in air temperature in all prediction models during the day in the period from 10h-22h. The decrease in air temperature ranges from -0.01ºC to -0.23ºC, which is a negligible change. The largest difference in air temperature occurs between the reference model and Model IV (model with implementation of all types of greenery) at 12 h. In the period from 23 h-5 h, when the heat accumulated in the soil and block structure is released, a slight increase in air temperature is seen in Models III and IV. In that period, the air temperature is lower than the optimal temperature, so this increase is favorable.

Analysis of the results for PET (Table 5), for the considered period during the day from 12 h-18 h, the warmest part of the day, shows there is a drop in PET in all prediction models. This change is smallest in Model I at -0.01ºC, and largest in Model IV at -4.2ºC. This leads to changes in the categorization of thermal sensation and physiological stress for Model III and Model IV, from strong to moderate heat for the time interval from 10 h-12 h and from 17 h-18 h.

It should also be noted that in Models III and IV there is a decrease in PET compared to the R-MODEL in the period from 7 h-18 h, for the duration of insolation. An additional feature of these models is that in the period from 19h-6h PET has higher values than PET of the basic model ranging from +0.4ºC to +0.91ºC, which leads to a change of PET category to a more favorable one.

Fig. 4 shows the differences in air temperature and PET prediction models (MODEL I, MODEL II, MODEL III, MODEL IV) compared to R-MODEL of the urban block.

The change of PET index in Model I and Model II compared to R-MODEL is small. For the considered Model II, the largest increase in PET is in the period from 21h-11h and amounts to +0.34ºC, and during the rest of the day, PET decreases compared to the baseline model by -0.03ºC. Model I shows the smallest deviation of the PET value compared to the basic model and ranges from 0.01ºC to 0.03ºC. This is due to the height difference between the ground floor where the measurement was taken and the roof level where the green roof is implemented in Model I. This result is in line with the results obtained by Müller et al. [31] which emphasizes that the application of green roofs on buildings over 10m high do not affect the change of PET at the level of the ground floor.

Depending on the position of the measuring point within the block, the values of AT and PET during the day obtained by simulations at that measuring point differ. Fig. 5 shows differences in air temperature and PET prediction models (MODEL I, MODEL II, MODEL III, MODEL IV) compared to R-MODEL of the urban block at points P1, P2, P3, P4, P5.

P1 Measuring Point

Model I shows the smallest change in AT compared to R-MODEL, as well as the smallest change in PET. In the period from 9h-6h, the AT of Model I is lower compared to AT reference model by a maximum of -0.11ºC, at 2 h while in the period from 6 h to 9 h the maximum increase of AT in Model I was +0.02ºC compared to the R-MODEL. As with the median PET values, the implementation of the green roof in Model I does not have a significant impact on the change in PET values compared to the base model. The largest difference between PET Model I and R-MODEL is -0.22ºC at 10 h.

Table 7. AT movement of all models for the observed measuring points during the day.

P1																								
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	15.4	14.3	13.3	12.8	12.2	12.1	13.9	16.3	19.8	23.3	26.3	29.3	31.3	32.9	33.4	34.0	33.2	31.9	29.6	27.0	24.7	22.4	20.4	18.2
MODEL I	15.3	14.3	13.2	12.7	12.1	12.0	13.9	16.3	19.8	23.3	26.2	29.3	31.3	32.9	33.4	34.0	33.2	31.9	29.6	27.0	24.6	22.4	20.4	18.2
MODEL II	15.3	14.3	13.2	12.7	12.1	12.0	14.0	16.4	20.0	23.3	26.4	29.3	31.3	32.9	33.3	33.9	33.1	31.8	29.5	26.9	24.6	22.4	20.3	18.1
MODEL III	15.4	14.3	13.3	12.8	12.2	12.1	14.0	16.3	19.6	22.9	25.9	28.8	31.1	32.7	33.4	33.8	33.1	31.7	29.5	27.0	24.6	22.4	20.3	18.2
MODEL IV	15.3	14.3	13.1	12.6	12.1	12.1	14.1	16.4	19.9	23.0	26.0	28.8	31.0	32.6	33.2	33.6	33.0	31.6	29.4	26.9	24.6	22.3	20.2	18.1
P2																								
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	15.4	14.4	13.6	12.9	12.3	12.1	14.2	16.5	20.8	23.7	27.4	29.2	31.6	33.2	33.6	33.8	33.1	31.7	29.6	27.0	24.7	22.5	20.4	18.1
MODEL I	15.4	14.4	13.5	12.9	12.3	12.1	14.2	16.5	20.8	23.6	27.4	29.2	31.6	33.1	33.5	33.8	33.1	31.7	29.6	27.0	24.6	22.4	20.4	18.1
MODEL II	15.4	14.4	13.5	12.9	12.3	12.1	14.3	16.5	21.0	23.7	27.4	29.2	31.6	33.1	33.5	33.8	33.1	31.6	29.5	27.0	24.6	22.5	20.5	18.1
MODEL III	15.4	14.4	13.7	12.9	12.3	12.1	14.4	16.4	20.0	23.0	26.5	28.7	31.1	32.9	33.5	33.6	33.0	31.6	29.5	26.9	24.6	22.4	20.4	18.4
MODEL IV	15.4	14.3	13.6	12.9	12.3	12.1	14.4	16.4	20.2	23.0	26.5	28.7	31.1	32.8	33.4	33.6	33.0	31.5	29.4	26.9	24.6	22.4	20.5	18.4
P3																								
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	15.4	14.4	13.7	12.9	12.2	12.1	14.1	16.4	19.7	23.3	26.5	28.7	31.5	32.7	33.4	33.6	33.1	31.7	29.6	27.0	24.7	22.5	20.5	18.2
MODEL I	15.4	14.4	13.6	12.9	12.2	12.0	14.1	16.4	19.7	23.3	26.4	28.6	31.5	32.6	33.4	33.6	33.1	31.7	29.6	27.0	24.7	22.5	20.5	18.2
MODEL II	15.4	14.4	13.6	12.8	12.2	12.1	14.2	16.5	20.0	23.4	26.5	28.7	31.5	32.6	33.4	33.6	33.1	31.6	29.5	27.0	24.7	22.5	20.5	18.1
MODEL III	15.4	14.4	13.7	13.0	12.3	12.1	14.1	16.4	19.6	23.1	26.2	28.6	31.1	32.5	33.3	33.5	33.0	31.6	29.5	26.9	24.7	22.4	20.5	18.2
MODEL IV	15.4	14.4	13.6	12.9	12.2	12.1	14.2	16.5	19.9	23.2	26.2	28.4	31.1	32.4	33.3	33.4	33.0	31.5	29.4	26.9	24.6	22.4	20.4	18.2
P4																								
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	15.4	14.4	13.3	12.8	12.3	12.2	14.0	16.4	20.1	23.4	26.4	29.2	31.6	32.9	33.4	34.2	33.3	31.8	29.7	27.0	24.8	22.5	20.4	18.1
MODEL I	15.4	14.4	13.2	12.8	12.3	12.2	14.0	16.4	20.1	23.4	26.4	29.2	31.6	32.9	33.4	34.2	33.3	31.8	29.6	27.0	24.8	22.5	20.4	18.1
MODEL II	15.4	14.3	13.1	12.7	12.3	12.1	14.0	16.5	20.2	23.5	26.4	29.2	31.5	32.8	33.3	34.1	33.2	31.8	29.6	27.0	24.7	22.4	20.3	18.1
MODEL III	15.4	14.4	13.3	12.8	12.3	12.1	14.0	16.4	19.7	22.9	26.1	28.9	31.2	32.9	33.4	33.9	33.2	31.7	29.6	27.0	24.7	22.5	20.4	18.3
MODEL IV	15.3	14.3	13.1	12.7	12.2.	12.1	14.1	16.5	20.0	23.0	26.1	28.9	31.0	32.8	33.4	33.8	33.1	31.6	29.5	26.9	24.6	22.4	20.2	18.1

Table 7. Continued.

	P5																							
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	15.4	14.3	13.2	12.6	12.1	12.1	13.9	16.4	20.2	23.4	26.6	29.3	31.6	32.9	33.4	33.9	33.2	31.7	29.6	27.0	24.7	22.4	20.3	18.1
MODEL I	15.3	14.3	13.1	12.6	12.1	12.0	13.9	16.5	20.2	23.3	26.5	29.2	31.5	32.9	33.3	33.9	33.1	31.7	29.6	27.0	24.7	22.4	20.3	18.1
MODEL II	15.3	14.3	13.1	12.6	12.1	12.0	14.0	16.5	20.3	23.4	26.6	29.2	31.5	32.9	33.3	33.8	33.1	31.7	29.5	27.0	24.7	22.4	20.3	18.0
MODEL III	15.4	14.3	13.2	12.7	12.1	12.1	14.0	16.4	20.0	23.0	26.4	29.1	31.4	32.8	33.4	33.7	33.1	31.7	29.5	27.0	24.6	22.4	20.2	18.2
MODEL IV	15.3	14.3	13.1	12.6	12.1	12.0	14.1	16.5	20.3	23.1	26.4	29.1	31.3	32.8	33.3	33.6	33.0	31.6	29.5	26.9	24.6	22.3	20.1	18.1

The AT of Model II is lower than the AT reference model in the period from 12 h-6 h while the PET of Model II is lower in the period from 13 h-18 h. The largest decrease of AT Model II is at 2 h and 17 h when the difference is -0.12ºC, and the largest decrease in PET is at 17 h when the difference is -0.29ºC. In the period from sunrise to noon AT of Model II is higher than AT of the reference model by a maximum of +0.15ºC, PET of Model II is higher than the PET of the reference model in the period from 20 h-13 h when the difference is +0.95ºC. The AT of Model III is lower than the AT of the reference model in the period from 7 h-23 h with the largest difference of -0.56ºC at 11h. PET of Model III is lower than PET of the reference model in the period from 7 h-18 h with the largest difference of -10.22ºC at 10 h.

AT of Model IV follows the trend of AT of Model III for most of the day, where AT of Model IV is on average lower than AT of Model III by 0.1ºC. Both models reach the largest AT difference of -0.56ºC compared to R-MODEL at 10 h. The largest increase in AT of Model IV compared to the base model is at 6h and amounts to +0.11ºC. PET of Model III and Model IV in the period from 9 h-17 h lead to changes in categorization of thermal sensation and physiological stress: from 9 h-10 h from mild heat to the category without thermal stress, from 10 h-12 h from extreme heat to moderate heat, from 12 h-16 h from extreme heat to strong heat and from 16 h-17 h from strong to moderate heat.

P2 Measuring Point

As with the previous measuring point, the smallest difference between AT and PET prediction models compared to the basic model occurs in Model I. The largest increase in AT of Model I in relation to R-MODEL is recorded at 7 h with +0.01ºC, while the largest increase in PET of the same model compared to the reference model is at 8 h with +0.05ºC. The largest decrease in AT of Model I compared to the R-MODEL is -0.07ºC at 14 h, and the largest decrease in PET is at 11h with -0.05ºC.

Model II shows the largest increase in AT and PET at 8h when AT amounts to +0.12 ºC and PET amounts to +0.33ºC compared to the R-MODEL. For the period when the values of AT and PET of Model II are lower than the reference model, we can observe the trend of hourly values of AT and PET of Model II compared to Model I. AT and PET values of Model III and IV are equal during the day, which can be seen in Fig. 5.

Models III and IV reach the largest differences of AT and PET compared to R-MODEL at an identical moment during the day. The greatest increase of AT in Models III and IV compared to R-MODEL is at 6 h when the AT of Model III measured +0.14ºC, and of Model IV +0.19ºC. Models III and IV have the largest PET increase at 5h: Model III +1.15ºC, and Model IV +1.31ºC. Models III and IV reach the largest AT decrease compared to R-MODEL at 10h: Model III -0.92ºC,

Table 8. PET oscillations of all models for the observed measuring points during the day.

P1	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	12.6	12.0	11.6	10.2	9.3	10.1	12.0	15.4	21.8	24.9	42.9	41.6	45.3	48.2	49.0	48.3	40.2	30.7	27.4	22.8	19.8	18.3	16.8	15.4
MODEL I	12.6	12.0	11.6	10.2	9.3	10.0	12.0	15.4	21.8	24.9	42.6	41.6	45.2	48.2	49.0	48.3	40.2	30.7	27.4	22.8	19.8	18.3	16.8	15.4
MODEL II	12.8	12.2	11.8	10.5	9.6	10.3	12.5	16.3	22.7	25.4	43.2	41.8	45.6	48.1	49.0	48.1	40.0	30.4	27.2	22.8	20.0	18.6	17.2	15.8
MODEL III	13.2	12.6	12.2	10.9	10.1	10.8	12.6	14.7	19.8	22.4	32.6	34.5	36.9	39.1	40.9	39.5	34.8	29.4	26.2	22.8	20.4	19.2	17.5	16.1
MODEL IV	13.3	12.7	12.3	11.0	10.3	10.9	12.9	15.3	20.6	22.9	33.0	34.7	37.1	39.1	40.9	39.4	34.7	29.2	26.2	22.8	20.6	19.4	17.6	16.2

P2	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	13.3	12.3	11.2	10.2	9.5	10.7	15.0	19.1	25.1	27.0	31.8	30.7	34.4	36.3	36.1	34.9	32.3	29.0	27.9	23.0	20.4	18.2	17.1	15.1
MODEL I	13.3	12.2	11.2	10.3	9.5	10.7	15.0	19.1	25.2	27.0	31.8	30.6	34.4	36.3	36.1	34.9	32.3	29.0	27.9	23.0	20.4	18.2	17.1	15.1
MODEL II	13.4	12.3	11.3	10.3	9.5	10.8	15.2	19.3	25.5	27.2	31.9	30.7	34.5	36.2	36.1	34.8	32.2	29.0	27.8	23.0	20.4	18.2	17.2	15.2
MODEL III	13.4	12.4	11.6	10.5	9.8	11.8	13.7	15.2	19.8	21.8	27.3	29.6	33.5	35.8	36.1	34.5	32.7	29.0	27.0	23.0	20.6	18.7	17.4	16.7
MODEL IV	13.4	12.4	11.6	10.6	9.9	12.0	13.9	15.4	20.1	21.9	27.4	29.6	33.6	35.7	36.0	34.5	32.7	28.8	27.0	23.0	20.6	18.8	17.5	16.9

P3	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	12.7	12.0	11.6	10.0	9.2	10.3	12.2	15.0	33.5	38.2	40.4	39.9	35.6	36.7	36.6	35.9	33.9	30.0	28.4	23.4	20.1	18.4	16.1	14.3
MODEL I	12.6	12.0	11.6	10.0	9.2	10.3	12.2	15.0	33.5	38.1	40.4	39.8	35.6	36.7	36.6	35.9	33.9	30.0	28.3	23.4	20.0	18.4	16.1	14.3
MODEL II	12.8	12.2	11.8	10.2	9.4	10.5	12.7	15.8	34.4	38.6	40.7	40.0	35.9	36.6	36.5	35.8	33.8	29.9	28.1	23.4	20.4	18.7	16.4	14.6
MODEL III	13.2	12.6	12.3	10.8	10.1	11.2	13.0	14.5	24.7	29.0	31.1	32.0	30.7	32.0	32.5	32.6	31.5	28.6	26.6	23.8	20.8	19.2	17.2	16.0
MODEL IV	13.2	12.6	12.4	10.8	10.2	11.3	13.3	14.8	25.3	29.3	31.3	32.0	30.9	32.0	32.4	32.5	31.4	28.6	26.6	23.8	20.8	19.3	17.3	16.1

P4	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	13.2	12.3	11.2	9.9	9.1	9.7	11.3	17.1	21.9	24.7	28.7	42.2	42.8	48.3	48.7	48.2	45.2	46.9	45.9	23.0	20.6	18.6	16.5	15.4
MODEL I	13.1	12.3	11.1	9.9	9.1	9.7	11.3	17.1	21.9	24.6	28.7	42.2	42.7	48.3	48.7	48.1	45.2	46.9	45.9	23.0	20.6	18.6	16.5	15.4
MODEL II	13.4	12.5	11.3	10.1	9.3	9.9	11.8	18.1	22.8	25.2	29.0	42.5	42.9	48.2	48.7	48.0	45.0	46.6	45.7	23.0	20.9	18.8	16.9	15.8
MODEL III	13.4	12.6	11.5	10.2	9.4	10.1	11.6	16.3	21.2	23.4	26.8	41.4	41.0	47.2	48.6	39.3	35.0	31.0	27.6	23.1	20.8	18.9	16.8	15.7
MODEL IV	13.6	12.8	11.6	10.4	9.7	10.3	12.0	17.2	22.0	24.0	27.2	41.7	41.2	47.3	48.6	39.1	34.8	30.8	27.5	23.2	21.0	19.2	17.1	16.0

Table 8. Continued.

	P5																							
	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
R-MODEL	12.1	11.3	10.2	8.9	7.9	8.6	13.8	14.9	30.9	32.1	35.7	38.5	41.0	39.8	40.6	46.5	31.4	29.0	25.2	22.8	19.2	16.8	16.0	14.3
MODEL I	12.1	11.3	10.1	8.9	7.9	8.6	13.8	14.9	30.9	32.0	35.7	38.5	40.9	39.8	40.6	46.5	31.4	29.0	25.2	22.8	19.2	16.8	15.9	14.3
MODEL II	12.2	11.3	10.2	9.0	8.1	8.7	14.1	15.4	31.4	32.4	35.9	38.6	41.1	39.8	40.6	46.4	31.3	28.8	25.0	22.8	19.4	16.8	16.2	14.5
MODEL III	12.6	11.7	10.6	9.2	8.2	9.2	14.5	15.2	30.4	32.0	34.9	38.1	39.7	40.8	33.3	33.7	30.7	28.6	25.6	23.8	19.6	17.4	16.4	15.9
MODEL IV	12.7	11.7	10.6	9.2	8.3	9.3	14.9	15.6	31.0	32.3	35.1	38.2	39.7	40.8	33.3	33.5	30.6	28.6	25.6	23.9	19.6	17.4	16.5	16.1

and Model IV -0.88°C, while the largest decrease in PET of these models at 8h were reached by Model III -5.36°C, and Model IV -5.13°C compared to the R-MODEL.

Table 8 gives the categorization of thermal sensation and physiological stress for all measurement points. Prediction Models III and IV affect the change in the categorization of thermal sensation and physiological stress during the day. In the period from 7 h-11 h, both Model III and Model IV record changes: from 7 h-8 h from the category without physiological stress to mild cold, from 8 h-10 h from mild heat to the category without physiological stress, from 10 h-11 h from moderate heat to mild heat. From 17 h-18 h, there is a change of category only in Model IV, from moderate heat to mild heat.

P3 Measuring Point

In P3 there is a clearer distinction of differences of the AT prediction models in relation to R-MODEL compared to measuring points P1 and P2. The differences between the prediction models and the reference model in PET can be observed in groups, namely Models I and II and Models III and IV.

Model I has the largest decrease compared to the AT of the reference model at 11h amounting to -0.09°C while the largest AT increase was recorded at 7 h, +0.02°C. When it comes to PET of Model I compared to R-MODEL, the largest decrease is at 6 h, -0.12°C, and largest increase at 8 h, +0.04°C.

The largest decrease in AT compared to the R-MODEL is seen in Model II at 8h, +0.22°C. The maximum reduction of Model II is -0.07°C at 2 h. The PET of Model II has its largest decrease at 18 h with -0.33°C compared to R-MODEL, and largest increase is at 9 h with +0.41°C.

The largest decrease in AT of Models III and IV occurs at the same time, at 10h, when the AT of Model III is -0.34°C, and AT of Model IV is -0.36°C. The largest increase in Model III occurs at 3 h with +0.08°C, and the largest increase in Model IV occurs at 6 h and 8h with +0.13°C. PET values of Model III and IV have the same trend in differences compared to PET of the reference model, so together they reach the largest decrease at 10h when PET of Model III is -9.26°C, and PET of Model IV -9.06°C. The largest increase in PET of Models III and IV is at 23 h when PET of Model III is +1.70°C and PET of Model IV is +1.80°C compared to R-MODEL.

Categorization of prediction Models I and II does not change compared to the categorization of the reference model. Models III and IV show changes during the night, from midnight to 1h when the category changes from moderate cold to mild cold. During the day, the categorization changes from 8h-18h. From 8 h-9 h there is a change of category from moderate heat to mild heat in both Model III and Model IV. From 9 h-10 h, Model III changes category from strong heat to mild heat, and Model IV changes from strong heat to moderate

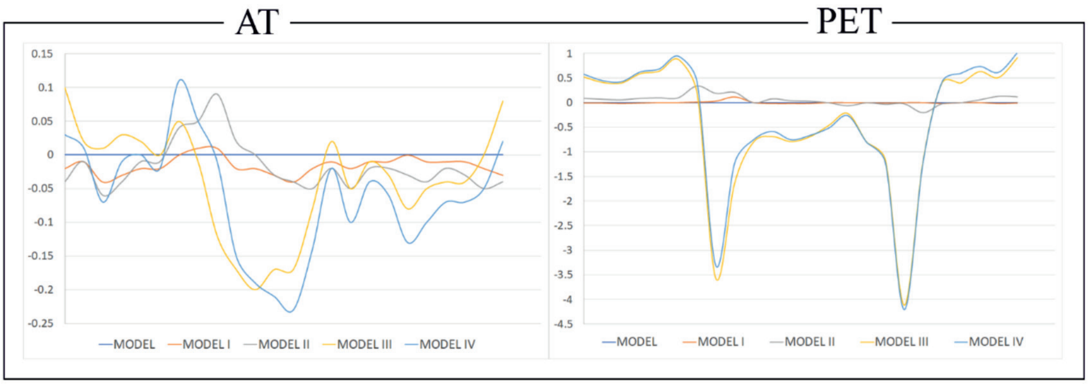

Fig. 4. Differences of median values of AT and PET MODEL I, MODEL II, MODEL III and MODEL IV compared to R-MODEL for period of 24 h.

heat. From 10 h-16 h, both models (III and IV) change category from strong heat to moderate heat, and from 17 h-18 h they change category from moderate heat to mild heat.

P4 Measuring Point

As with P1, P2 and P3, AT and PET of Model I are the closest to AT and PET of the reference model. Differences in AT between Model I and the reference model range from +0.02ºC at 7 h to -0.07ºC at 2 h, while PET ranges from +0.01ºC at 8 h to -0.05ºC at 2 h.

Model II shows the largest increase in AT and PET compared to R-MODEL. AT of Model II has the highest increase at 8 h compared to R-MODEL with +0.19ºC, and PET has highest increase at 7 h with +1.04ºC. The largest decrease in AT of Model II is at 2 h with -0.13ºC, while largest decrease in PET is at 6 h with -0.25ºC.

Models III and IV have the same PET movement trend, while in terms of AT there is a slight deviation from the trend. Largest increase in AT of Model III compared to R-MODEL occurs at 23 h with +0.13ºC, largest increase in AT of Model IV is at 6 h with +0.09ºC, while largest differences in PET of Model III and IV compared to R-MODEL are at 5 h when the difference in PET of Model III is +0.40ºC, and at 6 h when PET difference of Model IV is +0.70ºC. The largest decrease in AT of Model III compared to R-MODEL is at 9 h when with -0.52ºC, and Model IV at 12 h with -0.59ºC. The largest reduction in PET of both models compared to R-MODEL is at 18 h when Model III has a value of -18.29ºC and Model IV has -18.45ºC.

Model I and R-MODEL have no differences in categorization. P2 differs from the reference model in the period from 7 h-8 h and from 10 h-11 h. From 7 h-8 h there is a positive change of the category from mild cold to the category without physiological stress. From 10 h-11 h, there is a more unfavorable change compared to the R-MODEL when the mild heat category changes to the moderate heat category. Models III and IV have a significant difference compared to the R-MODEL. This difference is manifested in Model III from 12 h-13 h and in both models (Model III and Model IV) from 16 h-19 h. In the period from 12 h-13 h, Model III changes its category from extreme heat to strong heat. From 15 h-16 h, there is a change in the category of Model III and Model IV from extreme heat to strong heat. After that, in the period from 16 h-18 h, the category changes from extreme heat to moderate heat, and from 18 h-19 h, the biggest difference between the reference model and Models III and IV occurs when extreme heat changes to mild heat. This change in P4 is the biggest difference in terms of categorization of thermal sensation and physiological stress in the research.

P5 Measuring Point

The smallest oscillations of AT compared to the basic model are at P5. The difference between the AT of Model I and R-MODEL ranges from a maximum increase of 0.02ºC at 7 h to a maximum decrease of -0.06ºC at noon.

Model II records the largest increase in AT compared to R-MODEL, which at point P5 is +0.17ºC at 8 h, while the greatest decrease was recorded at 2 h and 12 h with -0.08ºC.

Model III has the largest increase in AT compared to R-MODEL of +0.09ºC at 23 h, and largest decrease of -0.35ºC at 9 h. Model IV records the same value of the largest difference reduction as Model III but records this extreme value at 15 h. The largest difference increase in AT of Model IV compared to R-MODEL is at 18 h with +0.15ºC.

The difference of PET prediction models compared to the R-MODEL gives highest values in Models III and IV which have a common maximum increase and decrease. The largest decrease is at 15 h with -13ºC in Model IV and -12.85ºC in Model III, and largest increase at 23 h in Model IV with +1.81ºC, and Model III with +1.57ºC.

The difference between PET of Model II and reference model ranges from +0.55ºC at 7 h and 8 h to -0.20ºC at 17 h and 18 h. The change in the difference between PET values of Model I is the smallest

Fig. 5. Differences of median values of AT and PET MODEL I, MODEL II, MODEL III, MODEL IV compared to R-MODEL for 24h at measuring points P1, P2, P3, P4 and P5.

compared to the base model with +0.03ºC at 7h to -0.06ºC at 12 h.

R-MODEL and Model I have the same hourly category distribution. Model II has two positive category changes. The first change in Model II compared to R-MODEL is at 4 h when the category shifts from strong cold to moderate cold. Another positive change in Model II is from 17 h-18 h, when there is a shift from moderate heat to mild heat. The negative change of the physiological stress category of Model II compared to R-MODEL occurs from 12 h-1 h when there is a change from strong heat to extreme heat. Model III records a change from 10 h-11 h compared to the category of physiological stress of the reference model from strong heat to moderate heat. The joint change of category of Model III and Model IV compared to R-MODEL occurs from 14 h-20 h. From 14 h-15 h, there is a change from strong heat to moderate heat. From 15 h-16 h, there is a change from extreme heat to moderate heat. From 17 h-18 h, the category changes from moderate heat to mild heat. From 19 h-20 h, the only negative change of Model III and Model IV compared to the category of physiological stress of the reference model occurs when there is a change from the category without physiological stress to mild heat.

Conclusions

The paper presents research that includes an analysis of the impact of the application of different forms of urban block greening on thermal comfort. Simulations of the reference model and prediction models (MODEL I, MODEL II, MODEL III, MODEL IV) were performed using the ENVI-met software package. The research was conducted on an urban residential block located in Nis, Republic of Serbia. The climate of the considered location is moderately continental. The research results show that:

The difference in the median temperature of the prediction models at the level of the URBAN block varies compared to the median temperature of the basic model from +0.11ºC to -0.23ºC, which does not represent a significant change;

Comparing the changes in air temperature of prediction models, we can see the similarity between Model I and Model II, as well as the similarity between Model III and Model IV. As Model IV represents a solution with the implementation of all types of greenery considered in the paper (roof greenery, facade greenery and ground floor greenery), we can conclude that the application of ground floor greenery used in prediction model III has the greatest impact on air temperature change of the researched area;

The difference of median PET prediction models at the block level varies in relation to the PET of the basic model from +0.91ºC to -4.2ºC, which leads to changes in the categorization of thermal sensation and physiological stress.

Comparing changes in PET prediction models, we can see the similarity in values of Model I and Model II, as well as the similarity between Model III and Model IV. The variation of Model I and Model II at the block level does not show significant changes compared to R-MODEL. The difference between PET values of Model III and Model IV and reference model at the block level is twofold. During the day, PET values of Models III and IV are lower than PET values of the reference model up to 4.2ºC, which reduces the category of physiological stress. During the night, PET values of these models are higher than the PET reference model. Both changes in PET have a positive effect on the researched location in terms of thermal sensation and physiological stress.

By selecting measuring points with different characteristics, air temperature and PET values were obtained for prediction models, as well as for the R-MODEL. The change in air temperature at measuring points between the prediction models and reference model did not show significant deviations from the median air temperatures at the level of the entire block. We can also notice similarities in the change of air temperatures during the day of Models I and II, as well as the shift of air temperatures of Models III and IV at all measuring points.

The difference between PET prediction models and the reference model at measuring points shows negligible changes in the prediction Models I and II and significant changes in the categories of thermal sensation and physiological stress in Models III and IV.

The differences between PET prediction models and the reference model give different extreme values of PET at different measuring points, which depend on the features of the measuring point (P1 from +0.95ºC to -10.22ºC, P2 from +1.31ºC to -5.36ºC, P3 from +1.80ºC to -9.26ºC, P4 from +1.04ºC to -18.45ºC, P5 from +1.81ºC to -13ºC).

During the day, in periods without insolation, P1, P2, P3, P4, P5 indicate an increase despite different features in terms of PET change, and during the insolation period indicate a decrease in PET compared to R-MODEL in Models III and IV, which has a positive effect on thermal comfort of the area user.

As only one urban residential block was analyzed in the paper, the conclusions obtained cannot be used for all types of urban blocks. The further course of research includes the analysis of different types of urban residential blocks and the comparison of results with the results obtained in this paper. The meteorological data based on which the simulations were performed refer to the period from 1991 to 2010 for solar radiation, and from 2000 to 2009 for air temperature. As the air temperature increases due to global warming, the new research will include weather data for the period from 1996 to 2015 for solar radiation and from 2000 to 2019 for air temperature. Based on this, a comparative analysis of the results from the given period will be performed which can, in turn, lead to a conclusion in order to predict the temperature trend in the coming years, as well as to select the most favorable models in order to reduce the heat island effect and achieve PET that provides less physiological stress.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. ANGOTTI T. Metropolis 2000. London, UK: Taylor & Francis Ltd. **1993**.
2. DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS. World Urbanization Prospects the 2018 Revision. New York. Retrieved from https://population.un.org/wup/Download/ **2019**.
3. CHEN L., ZHANG M., ZHU J., WANG Y., SKOROKHOD A. Modeling Impacts of Urbanization and Urban Heat Island Mitigation on Boundary Layer Meteorology and Air Quality in Beijing Under Different Weather Conditions. Journal of Geophysical Research: Atmospheres, **123** (8), 4323, **2018**.
4. LIU Y., LI T., PENG H. A new structure of permeable pavement for mitigating urban heat island. Science of the Total Environment, **634**, 1119, **2018**.
5. KATO S., YAMAGUCHI Y. Analysis of urban heat-island effect using ASTER and ETM+ Data: Separation of anthropogenic heat discharge and natural heat radiation from sensible heat flux. Remote Sensing of Environment, **99** (1-2), 44, **2005**.
6. FILHO W.L., ADAMSON K., DUNK R.M., AZEITEIRO U.M., ILLINGWORTH S., ALVES F. Implementing Climate Change Adaptation in Cities and Communities. Climate Change Management. **2016**.
7. CHEN J., CHU R., WANG H., ZHANG L., CHEN X., DU Y. Alleviating urban heat island effect using high-conductivity permeable concrete pavement. Journal of Cleaner Production, **237**, 117722, **2019**.
8. YUAN C., ADELIA A.S., MEI S., HE W., LI X.X., NORFORD L. Mitigating intensity of urban heat island by better understanding on urban morphology and anthropogenic heat dispersion. Building and Environment, **176**, 106876, **2020**.
9. BERNARD J., MUSY M., CALMET I., BOCHER E., KERAVEC P. Urban heat island temporal and spatial variations: Empirical modeling from geographical and meteorological data. Building and Environment, **125**, 423, **2017**.
10. GÜRLÜK S., UZEL G., TURAN Ö. Impacts of Cattle and Sheep Husbandry on Global Greenhouse Gas Emissions: A Time Series Analysis for Central European Countries. Polish Journal of Environmental Studies, **2015**; **24** (1), 93, doi.org/10.15244/pjoes/30265
11. APREDA C., REDER A., MERCOGLIANO P. Urban morphology parameterization for assessing the effects of housing blocks layouts on air temperature in the Euro-Mediterranean context. Energy and Buildings, **223**, 110171, **2020**.
12. NURUZZAMAN M. Urban Heat Island: Causes , Effects and Mitigation Measures -A Review Urban Heat Island : Causes, Effects and Mitigation Measures - A Review. International JOurnal of Environmental Monitoring and Analysis, **3** (2), 67, **2015**.
13. TAKEBAYASHI H., MORIYAMA M. Study on the urban heat island mitigation effect achieved by converting to grass-covered parking. Solar Energy, **83** (8), 1211, **2009**.
14. CA T.V., ASAEDA T., ABU E.M. Reductions in air conditioning energy caused by a nearby park. Energy and Buildings, **29** (1), 83, **1998**.
15. JAMEI E., RAJAGOPALAN P., SEYEDMAHMOUDIAN M., JAMEI Y. Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. Renewable and Sustainable Energy Reviews, **54**, 1002, **2016**.
16. BLANCO I., SCHETTINI E., MUGNOZZA G.S., VOX G. Thermal behaviour of green façades in summer. Journal of Agricultural Engineering, **49** (3), 183, **2018**.
17. PENG L.L.H., JIANG Z., YANG X., HE Y., XU T., CHEN S.S. Cooling effects of block-scale facade greening and their relationship with urban form. Building and Environment, **169**, 106552, **2020**.
18. MUTANI G., TODESCHI V. The Effects of Green Roofs on Outdoor Thermal Comfort, Urban Heat Island Mitigation and Energy Savings. Atmosphere, **11** (2), **2020**.
19. HERATH H.M.P.I.K., HALWATURA R.U., JAYASINGHE G.Y. Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy. Urban Forestry and Urban Greening, **29** (March 2017), 212, **2018**.
20. GÓMEZ F., CUEVA A.P., VALCUENDE M., MATZARAKIS A. Research on ecological design to enhance comfort in open spaces of a city (Valencia, Spain). Utility of the physiological equivalent temperature (PET). Ecological Engineering, **57**, 27, **2013**.
21. KNAUS M., HAASE D. Green roof effects on daytime heat in a prefabricated residential neighbourhood in Berlin, Germany. Urban Forestry and Urban Greening, **53** (September 2019), 126738, **2020**.
22. BRUSE D. Decoding Urban Nature. (L. Zech & G. Bettio, Eds.). Essen: ENVI_MET GmbH. **2017**.
23. DENG J.Y., WONG N.H. Impact of urban canyon geometries on outdoor thermal comfort in central business districts. Sustainable Cities and Society, **53**, 101966, **2020**.
24. SALATA F., GOLASI I., DE LIETO VOLLARO R., DE LIETO VOLLARO A. Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. Sustainable Cities and Society, **26**, 318, **2016**.
25. HOPPE P. The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. International journal of biometeorology, **43** (2), 71, **1999**.
26. RODRÍGUEZ-ALGECIRAS J., TABLADA A., CHAOS-YERAS M., DE LA PAZ G., MATZARAKIS A. Influence of aspect ratio and orientation on large courtyard thermal conditions in the historical centre of Camagüey-Cuba. Renewable Energy, **125** (September), 840, **2018**.
27. OUYANG W., MORAKINYO T.E., REN C., NG E. The cooling efficiency of variable greenery coverage ratios in different urban densities: A study in a subtropical climate. Building and Environment, **174**, 106772, **2020**.
28. CHATTERJEE S., KHAN A., DINDA A., MITHUN S., KHATUN R., AKBARI H., WANG Y. Simulating micro-scale thermal interactions in different building environments for mitigating urban heat islands. Science of the Total Environment, **663**, 610, **2019**.
29. LALOŠEVIĆ M.D., KOMATINA M.S., MILOŠ M.V., RUDONJA N.R. Green roofs and cool materials as

retrofitting strategies for urban heat Island mitigation - Case study in Belgrade, Serbia. Thermal Science, 2018(**6**), 2309, **2018**.

30. PARSONS K.C. Introduction to thermal comfort standards. Retrieved from http://www.utci.org/cost/publications/ISO Standards Ken Parsons.pdf **(n.d.)**
31. MÜLLER N., KUTTLER W., BARLAG A.B. Counteracting urban climate change: Adaptation measures and their effect on thermal comfort. Theoretical and Applied Climatology, **115** (1-2), 243, **2014**.