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THE INFLUENCE OF BUILDING ENVELOPE ON THE LOCAL MICROCLIMATE

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ABSTRACT. Urban areas have higher temperatures than the surrounding suburban/rural areas, a phenomenon known as the Urban Heat Island (UHI). There is a great interest in creating a healthy and comfortable environment for the growing number of urban dwellers to live in, therefore different methods of combating and diminishing the urban heat island are being studied. One such method is to reduce the energy contribution of buildings to the formation of the urban heat island. In this paper we analyzed the effect of building envelopment, both by seasonal monitoring of surface temperatures using the thermal camera at different time intervals, and by numerical simulations of air temperature at different levels in the atmosphere, using ENVI-met, a three-dimensional non-hydrostatic microclimatic model. The data sets resulting from the monitoring of the surface temperature with the thermal camera showed that the temperature recorded at the surface is lower for the enveloped buildings than for the non-enveloped buildings, during the night but also during the day, less at noon. The numerical simulations were based on two scenarios: i) buildings with non-enveloped walls and ii) the same buildings but with enveloped walls, after running the scenarios for enveloped and non-enveloped buildings. The results showed that following the enveloping process the air temperature in the areas between the buildings is lower for the enveloped buildings, at different heights, both during the night and during the day.

Keywords: urban microclimate; simulation; urban morphology; ENVI-met

1. INTRODUCTION

Climate change is a serious problem facing humanity today (IPCC, 2019). The trend of global warming has been observed since the middle of the twentieth century, with the industrialization and evolution of human society, and affects especially, but not exclusively, the inhabitants of urban areas where the phenomenon of urban heat island (UHI), characterized by average temperatures in higher cities than in the surrounding rural areas, it is intensified. Factors that contribute to the phenomenon are: the geographical location of the urban area, the time of day (UHI is higher at night), synoptic conditions (high pressure, clear sky, light wind and no precipitation), anthropogenic heat resulting from combustion processes such as road traffic,

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residential and industrial heating, even that generated by the use of air conditioners, urban designs, geometry and paving of roads, the shape and materials of buildings, and changes in land use and land cover (Arnfield, 2003; Grigoraș & Urițescu, 2018, 2019; Oke, 1988; Rizwan et al., 2008; Santamouris, 2014).

Given the frequency and amplitude of heat waves and UHI, as well as the important environmental, energy and health implications of UHI, ensuring the thermal comfort of a growing urban population has become a research topic of great interest(Huang et al., 2021). In order to improve the comfort of living in the urban areas, as well as to reduce the risks associated with health and the environment, a number of measures to mitigate the heat island have been studied and proposed by various researchers (Aram et al., 2019; Kim & Brown, 2021; Koch et al., 2020; Wang, 2021). Some of these could be implemented in the urban design and planning phase such as the geometry and morphology of the city, another part could be implemented on existing situations: extension of green and blue infrastructure (which refers to green walls, green roofs, trees and hedges, bodies of water), and the increase of surface albedo (the use of materials with high reflectivity for roofs, pavements and other surfaces at ground level). Green infrastructure helps to reduce the impact of the UHI effect through cooling effects such as shading, evapotranspiration and higher leaf reflectivity than black building materials (Aram et al., 2019; Gunawardena et al., 2017; Manso et al., 2021; Teotónio et al., 2021). The use of vegetation as a measure to mitigate the heat island phenomenon can be achieved at different spatial scales, from extensive urban parks to street trees, grass yards, green roofs and green wall. Urban structures made of concrete, asphalt, metal, etc., absorb solar radiation, therefore they heat and radiate heat, being responsible for higher air and surface temperatures. Increasing the solar reflectivity of urban surfaces is an already popular urban cooling technique. This can be done by replacing conventional roofing and paving materials with "cold materials" with high sun reflectance. Also, the use of cold materials for building envelopes reduces the heat transfer through walls and roofs, the summer having a beneficial effect on the thermal conditions inside the buildings (Jandaghian & Akbari, 2021; Manni et al., 2020; Salvati et al., 2022).

This article investigates the effect of urban building envelope on surface temperature and air temperature in Bucharest area, the capital of Romania, a city where the UHI phenomenon has been frequently observed and studied (Cheval & Dumitrescu, 2015; Grigoraș & Urițescu, 2018; Urițescu et al., 2019; Tumanov et al., 1999). Enveloped surface temperature versus non-enveloped surface temperature was monitored using an infrared thermal imaging camera, FLIR T350. Also, the influence of building envelope on the urban microclimate was achieved by numerical simulations of air temperatures at different levels and time limits using the ENVI-met model. (Yang et al., 2013). Using the ENVI-met model to quantify the possible increase in thermal comfort as a result of the implementation of UHI mitigation measures is a cost-effective efficiency method that is increasingly used (Crank et al., 2018; Forouzandeh, 2021).

2. DATA AND METHODS

Investigation the effect of buildings envelope, as a possible strategy for attenuating the urban heat island, was carried out by monitoring the surfaces temperature of the enveloped and non-enveloped buildings using the FLIR T350 thermal camera. Also, the influence of building envelope on the local microclimate was highlighted by temperature simulations performed with the ENVI-met model.

2.1. Study area

The analyzed area, illustrated in Figure 1, represents a typical Bucharest block of flats in the southwestern part of the city, made up of buildings with a height of 11, 9 and 5 floors, occupying an area of 14,400 m^2. For the correct realization of the digital 3D model used in numerical simulations, satellite images from the Google Earth application were used and field measurements were performed.

Fig. 1. Location of the study area

2.2. Data used

2.2.1. Temperature monitoring with thermal camera

The monitoring was performed with a FLIR T350 camera, equipped with an infrared detector, with a large temperature range (from -20 ° C to 650 ° C), with an accuracy of +/- 2 ° C, which makes images in natural colors at a resolution of 1280 x 1024 pixels and thermal infrared images at a resolution of 320 x 240 pixels (TEquipment, 2015).

With the help of the FLIR T350 camera, images were captured every 6 hours, on different days of the four seasons. The images selected for this study were taken on January 28, 2021, May 7, 2021, August 1, 2021 and October 27, 2021, one day for each of the four seasons. The analyzed days were also selected due to the weather conditions (clear days without precipitation or clouds were selected, which would have influenced the temperature of the analyzed surfaces).

2.2.2. ENVI-met

Numerical simulations of air temperature, in order to highlight the influence of building envelopes on them, were performed using the ENVI-met program (http://www.envi-met.com/). ENVI-met is a three-dimensional microclimate model, based on the fundamental laws of fluid dynamics and thermodynamics, designed to simulate complex surface-vegetation-air interactions in the urban environment.

For the numerical simulations in the ENVI-met model, information recorded at the Filaret meteorological station, which belongs to the National Meteorological Administration, was used for the following meteorological parameters: wind speed, air temperature and relative humidity. The values used for the roughness length and specific humidity at the upper level of the model were those defined by default in ENVI-met. Numerical stability of the model and minimization of boundary effects that may affect the output data were ensured by placing several cell networks around the main modeling area. The main modeling range was 100 (X) * 100 (Y) * 40 (Z), with a pitch of 1.2 m for each horizontal direction (Figure 2).

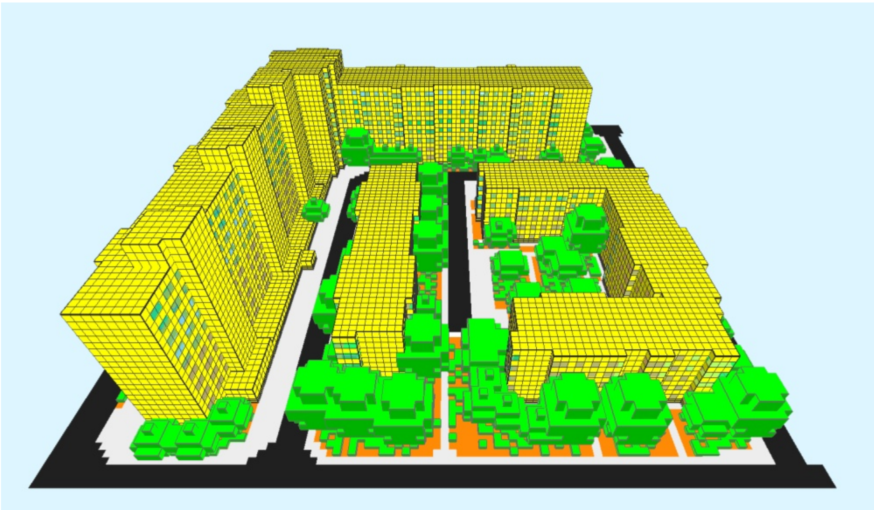

Fig. 2. ENVI-met 3D model of the analyzed area

In the 3D model were introduced types of surfaces (asphalt, concrete, soil), vegetation (grass and trees - species and dimensions) and buildings (residential and power transformers).

In order to create scenarios as close as possible to reality, the materials and dimensions of the walls of the buildings were taken into account, as well as the covering materials. Therefore, in the numerical simulations, for each building layer (precast reinforced concrete, autoclaved aerated concrete-CCA, polystyrene and insulating layers) values were introduced for the necessary parameters: Default Thickness, Absorption, Transmission, Reflection, Emissivity, Specific Heat, Thermal Conductivity, Density.

Their order was also taken into account in the composition of the walls for the two scenarios analyzed (enveloped and non-enveloped). For each scenario, runs were made for two time periods: 01:00, 19:00, local time. The day of August 1, 2021, the hottest day with clear skies of that year for Bucharest, was chosen for the numerical simulations.

3. RESULTS AND DISCUSSIONS

The effects of building envelope were studied both by in situ monitoring of the surface temperatures of adjacent buildings (one enveloped and the other non-enveloped) at four times in the four seasons and by simulations of air temperature at different levels, using the 3D model for microclimate urban, ENVI-met.

3.1. Temperature monitoring with the help of the thermal camera

Images were taken to highlight and monitor the thermal differentiations between enveloped and non-enveloped buildings of 9 floors (ground floor + 8 floors) each, located very close to each other. The images were captured at 1:00, 7:00, 13:00 and 19:00, local time, on January 28, May 7, August 1 and October 27, 2021. The results of this monitoring are shown in Figure 3, the temperature values recorded for the surface of the side walls being summarized in Table 1.

Table 1. Temperature values for the side walls surfaces

Non-enveloped surface				
hour/ day	2021-01-28	2021-05-07	2021-08-01	2021-10-27
1:00	-3 °C - +10 °C	+18 °C - +21 °C	+33 °C - +37 °C	+10 °C - +15 °C
7:00	-5 °C - +7 °C	+12 °C - +18 °C	+26 °C - +31 °C	+8 °C - +13 °C
13:00	-2 °C - +11 °C	+19 °C - +24 °C	+29 °C - +39 °C	+11 °C - +16 °C
19:00	+2 °C - +13 °C	+26 °C - +31 °C	+34 °C - +42 °C	+12 °C - +17 °C
Enveloped surface				
hour/ day	2021-01-28	2021-05-07	2021-08-01	2021-10-27
1:00	-10 °C - -5 °C	+10 °C - +13 °C	+28 °C - +30 °C	+2 °C - +6 °C
7:00	-16 °C - -12 °C	+5 °C - +8 °C	+20 °C - +23 °C	+1 °C - +4 °C
13:00	+10 °C - +21 °C	+28 °C - +32 °C	+46 °C - +52 °C	+13 °C - +18 °C
19:00	-10 °C - -2 °C	+18 °C - +23 °C	+29 °C - +33 °C	+9 °C - +12 °C

For **January 28, 2021**, the image taken at 1:00 shows differences of maximum 15°C between the 2 categories, for the non-enveloped surface recording temperature values of the wall surface from -3°C to +10°C, and for the enveloped surface values range from -10°C to -5°C, which is due to the properties of the concrete that captures and stores solar radiation, converting it into heat, which is emitted during the day (morning, afternoon) but especially in the night. The same differences between the surfaces can be seen in the image taken at 7:00, but with different values: from -5°C to +7°C for the non-enveloped surface and values from -16°C to -12°C for the enveloped surface, resulting in the conclusion that the concrete emits heat accumulated throughout the night, thus cooling the walls of the building and probably the ambient temperature in the apartments, while the enveloped surfaces do not change their temperature, not being influenced by the low values during the night and thus proving their usefulness in their role of maintaining the ambient temperature in houses.

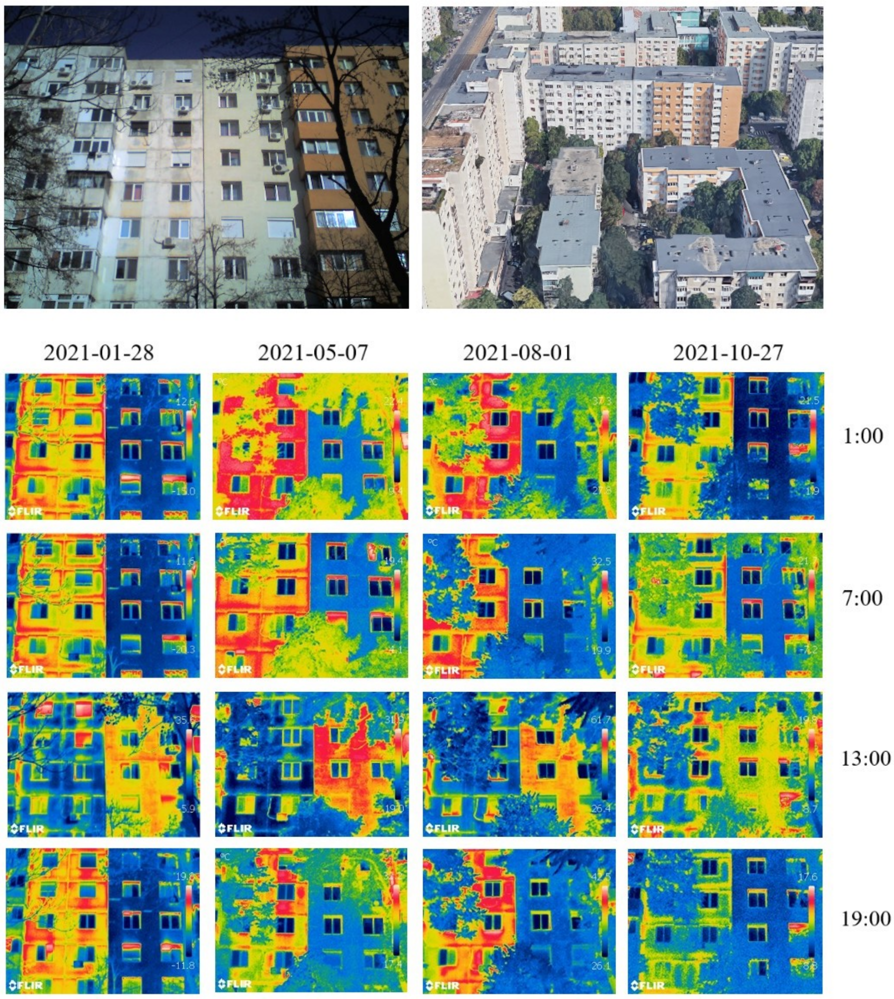

Fig. 3. Side wall surface temperature variation for non-enveloped building (left) and enveloped building (right)

At 13:00, from the image taken at that time, there is a difference in the values recorded on the surface of the walls compared to previous periods, so that in the case of the uncoated surface the temperatures register values from -2°C to +11°C and for surface area, values from +10°C to +21°C are observed. This temperature inversion between the 2 surfaces is due to the properties of concrete layers that are heating much slower than the enveloped surface (a difference of about 3°C for non-enveloped walls, compared to about 10°C for enveloped walls). These values and differences are changing in the following hours, so that at 19:00, when the last image is taken for the same area, in the case of the non-enveloped surface, temperature values range from +2°C to +13°C, and for the enveloped surface, values from -10°C to -2°C are recorded, thus resulting in the conclusion that the non-enveloped concrete surfaces remain heated for a good period of time during a day compared to the enveloped surface.

For **May 7, 2021**, the image taken at 1:00 shows temperature differences on the surface walls that range between +18°C and +21°C for the non-enveloped buildings, while for the enveloped surface the recorded temperature range from +10°C to +13°C. For the image recorded at 7:00 in the case of the non-enveloped surface, temperature has values from +12°C to +18°C hence the fact that the concrete surfaces not only store and emit heat during the night, but the temperature drop is very slow for warmer periods. For the enveloped surface a more obvious decrease is observed, the temperature values vary between +5°C and +8° C. In the case of the image recorded at 13:00, the highest temperature values are observed for both surfaces analyzed. In the case of the non-enveloped surface, the values increased up to +24°C, and for the enveloped surface, they reach +32°C. As previously explained in the case of the images from January 27, the thermal insulation layers heat up much faster in the first part of the day than the non-enveloped concrete walls. In the case of the last image taken, the one from 19:00, in the case of the non-enveloped surface, temperature values from +26°C to +31° C are registered, and for the enveloped surface values range from +18°C to +23°C.

For **August 1, 2021**, the image obtained at 1:00 shows temperature differences up to 7°C between the 2 types of surfaces. In the case of the non-enveloped surface the temperature varies between +33°C and +37°C, while for the enveloped surface the temperature values range from +28°C to + 30°C. Same difference was obtained for the image taken at 7:00, when in the case of the non-enveloped surface, the temperature range from +26°C to +31°C, and in the case of the coated surface values from + 20°C to + 23°C. In the case of the image obtained at 13:00, the highest values are recorded; in the case of non-enveloped surface, the temperatures reach values up to +39°C, and for the enveloped surface, they reach up to + 52°C. For the last image taken, the one from 19:00, at the level of the non-enveloped surface, temperature range from + 36°C to +47°C, and for the other type, from + 29°C to +33°C. This shows that in the warmer months, the concrete surfaces, after capturing the radiation from the sun during the day, become true furnaces during the night, the difference between the values recorded during the day and those recorded during the night, being about 16°C, much lower than in the case of enveloped surfaces, where the difference is 22°C.

For **October 27, 2021**, from the image taken at 1:00 it is observed that the surface temperature varies between +10°C and +15°C for the non-enveloped surface, while for the enveloped surface the recorded temperature values are included between +2°C and +6°C. For the image recorded at 7:00, the same decreasing trend is observed as in the other days analyzed; in the case of the non-enveloped surface, the temperature has values from +8°C and +13°C, and for the enveloped surface, the temperature range between +1°C to +4°C. In the case of the image recorded at 13:00, for the non-enveloped surface the values have increased and varies from +11°C to +16°C, and for the enveloped surface, the temperature range from +13°C to +18°C. In the case of the last image obtained, temperature has values from +12°C to +17°C and for the non-enveloped surface, from +9°C to +12°C for the other type.

These characteristics of the temperature's evolution for the 2 categories of surfaces are also observed in the case of the last analyzed day, following the pattern resulting from the analysis of previous images: during the night, higher temperature values are observed at the level of non-enveloped concrete surfaces, due to its properties of maintaining the solar radiation received during the day and emitting it into the atmosphere in the form of heat. This continues in the morning of the analyzed days, when the enveloped surfaces have lower temperature values. Although the layers of thermal insulation materials heat up faster than the concrete walls during the afternoon, towards the end of the day, they cool faster, so the non-enveloped surface contributes more to the generation of heat and high values of surface temperature thus of air temperature during at night, but also to maintain the phenomenon of UHI.

3.2. Simulation of air temperatures using the ENVI-met model

For an analysis of the influence of surface types on air temperature, two comparative simulations were performed for the same area, based on two scenarios: a scenario in which the walls of buildings are not-enveloped and a second scenario for the same buildings, but with enveloped walls. The interval when the two simulations were run are night (01:00) and afternoon (19:00), considered two periods when the UHI phenomenon is very visible. The analyzed area represents a typical Bucharest block area and includes the horizontal range of 100 m x 100 m and the vertical range up to a height of 40 m, in which for levels of heights were analyzed: 2 m, 5 m, 10 m, and 20 m. The date when the scenarios were run is August 1, 2021, the hottest clear day of that year for Bucharest.

Figure 4 shows the temperature at a height of 2 m, 5 m, 10 m and 20 m resulting from simulations for 19:00. From the simulation results, in the analyzed area it appears that between the 2 categories of blocks there are differences in air temperature for all 4 analyzed heights.

At 2 m height, for the scenario of non-enveloped buildings, the temperature range between +32.5°C and +33.9°C, while in the case of enveloped buildings, the air temperature has values from +32.2°C to +33.9°C; extreme values are found in shaded areas or in the areas exposed to the sun. The areas that were shaded until the analyzed time, have temperatures with similar values for the 2 scenarios, these being located on small areas. Between buildings, the air temperature is lower in the case of enveloped buildings scenario, with about 0.6 - 0.8 ° C in the vicinity of the walls of buildings. In the rest of the area the differences range from 0 to 0.5°C depending on the types of surfaces and their size (streets, alleys, buildings gardens). From the resulting maps it can be seen that the air temperature is considerably influenced by the temperature at the ground surface, especially at a height of 2 m, where the highest variation of air temperature is observed, for both scenarios.

From the resulting maps at the 5 m height, there are differences from the previous scenario, for both types of building categories. For non-enveloped buildings the temperatures range from +32.7°C to +33.8°C, and in the case of enveloped buildings, from +32.3°C to +33.8°C. The differences between the 2 scenarios for the 2 types of buildings range from 0.4°C in areas that have been shaded for much of the day, to 0.5°C in areas without shade.

From the resulting maps for the height of 10 m, for the non-enveloped buildings, there is an increase of the minimum values and a decrease of the maximum ones, these having a variation between +32.8°C and +33.7°C. The same can be seen in the scenario with enveloped buildings, where the temperatures range from +32.4°C to +33.6°C. Compared to the previous ones, in the case of the scenario made for the height at 10 m, a slight uniformity of the distribution of temperature values for the analyzed area can be observed. Both the maximum and the minimum for both scenarios being distributed over smaller areas than the previous heights. The biggest differences can be observed in the center of the analyzed area and in the proximity of the buildings.

At 20 m height, an increase in the minimum values and a decrease in the maximum values mentioned above can be observed: in the case of non-enveloped buildings the temperature varies between +33.2°C and +33.8°C while for the scenario with enveloped buildings, temperatures range from +32.8°C to +33.4°C. As in the previous case, there is a uniformity of air temperature for both types of buildings, the largest temperature differences between the two being about 0.5°C, being found in the vicinity of the buildings, resulting in the conclusion that during the day the enveloped buildings do not influence the increase of the air temperature around them as do the non-enveloped ones.

Figure 5 shows the temperature at height of 2 m, 5 m, 10 m, and 20 m resulting from simulations for 01:00. From the results, in the analyzed area it appears that between the 2 categories of envelope buildings there are differences in air temperature for all 4 heights analyzed, similar as in the case of the simulations from 19:00, but on a smaller area.

At 2 m height, in the case of non-enveloped buildings, the temperature range from +27.2°C to +29.5°C, while for the enveloped buildings, the air temperature range between +27°C and +29.1°C. The largest differences of about 0.4°C and is located in the areas between buildings and in the proximity of the walls that have been exposed to the sun for a longer period.

The resulting maps for the height of 5 m show the same pattern as in the previous scenario, for both types of building, expressed by the extension of areas with high temperatures more obvious in the case of non-envelope buildings and the decrease of areas with low temperatures, air temperature variation between +27.7°C and

+29.6°C for non-enveloped buildings, and a variation between +27.5°C and +29.1°C for the enveloped buildings.

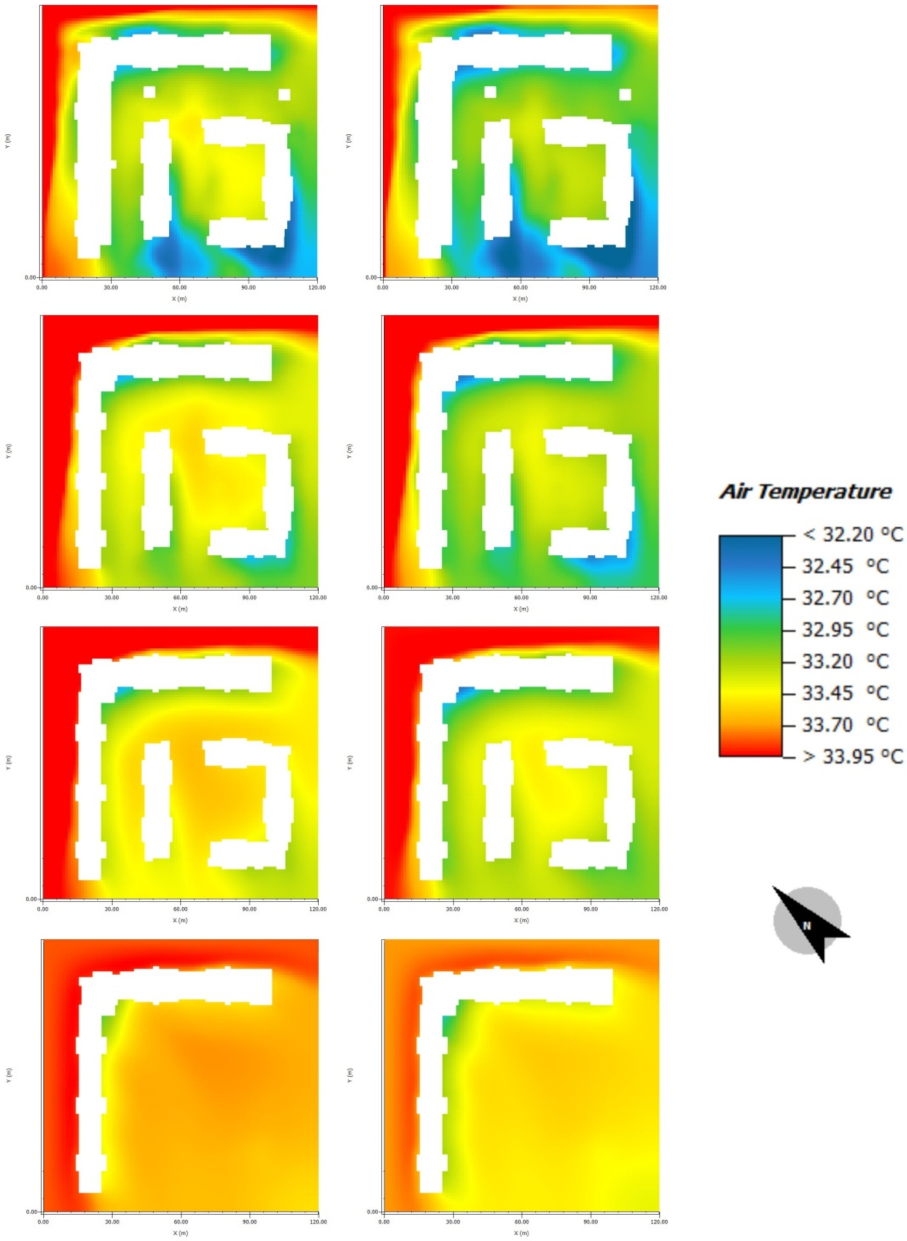

***Fig. 4.** Air temperature for non-enveloped (left) and enveloped (right) buildings at 19:00 at height of 2 m (top), 5 m (middle-top), 10 m (middle-bottom), 20 m (bottom)*

From the resulting maps for the height of 10 m, an increase in air temperature values for the two types of buildings can be observed, which have a variation between

+28.1°C and +29.6°C in the case of non-enveloped buildings, and a variation between +27.9°C and +29.2°C for enveloped buildings. As in the previous case, higher values of air temperature are observed over a larger area in the case of non-enveloped buildings.

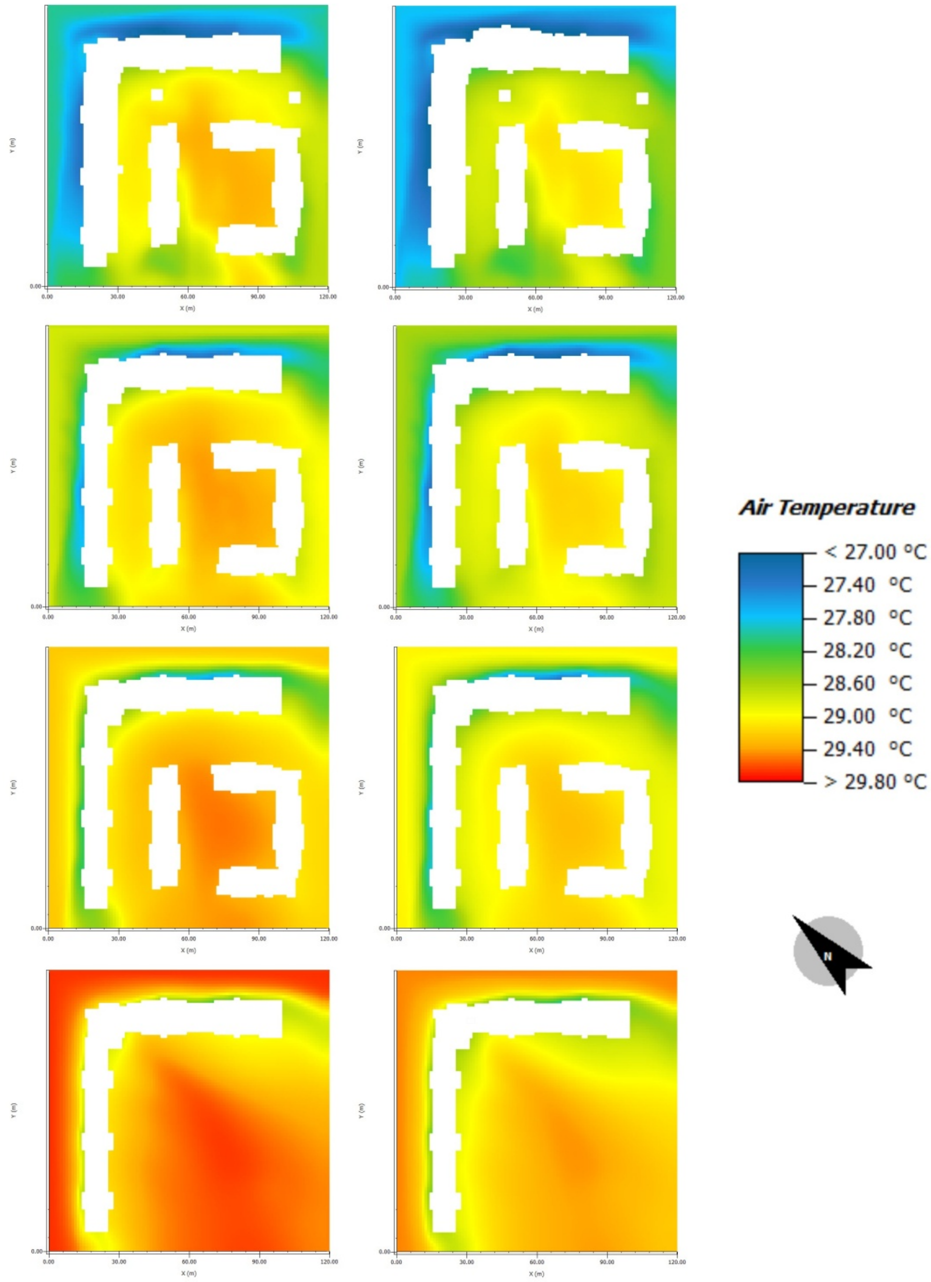

Fig. 5. Air temperature for non-enveloped (left) and enveloped (right) buildings at 1:00 at height of 2 m (top), 5 m (middle-top), 10 m (middle-bottom), 20 m (bottom)

For the height at 20 m, an increase of values for both categories of buildings can be observed: from +28.6°C to +29.8°C for the non-enveloped buildings, and from +28°C to +29.4°C for the other category. The resulting maps for 01:00 shows the same pattern between the two categories of buildings: the air temperatures are higher for non-enveloped buildings (as in the scenario for 19:00), only this time in the proximity of the walls, the differences between the two types of buildings range from 0.5 to 0.9°C. A major difference for 01:00 from the previous scenarios is the increase in air temperature with the increase in altitude, especially for the maximum values. This is due to the walls of buildings that store heat during the day and release it during the night but also indicate a vertical stratification of it, at the level of the roofs and the upper contact limit ("CANOPY LAYER") of the UHI phenomenon.

4. CONCLUSIONS

In recent decades, many UHI mitigation strategies have been designed and implemented to improve the quality of the urban environment, which can be broadly classified as infrastructure: white (high solar reflectivity materials), green (vegetation-covered areas) and blue (water-covered surfaces). Increasing the solar reflectivity of the urban surfaces is at the forefront of urban cooling techniques because it can be achieved on existing situations and structures, without changes in the geometry of the city and without urban landscape changes.

The paper analyzed the effect of buildings envelope as a measure implemented to reduce the heat island intensity in already built urban areas. The study area is represented by a small part of a neighborhood in the southwest of Bucharest, with characteristics typical of block of flats.

The influence of building envelope on the urban microclimate was highlighted: i) on the one hand by thermal monitoring for a period of one year, at several times of the day (01:00, 7:00, 13:00 and 19:00) of the surface temperatures of some enveloped and non-enveloped buildings; ii) and on the other hand, by simulating the air temperature using the ENVI-met model, a Computational Fluid Dynamics (CFD) model that relies on RANS equations to solve for atmospheric flow and heat transfer in urban settings. Simulations were performed for two time periods (01:00 and 19:00, local time) and four height levels (2 m, 5 m, 10 m, and 20 m) were analyzed for the two scenarios: non-enveloped buildings and enveloped buildings.

From the images taken with the infrared thermal camera, at different times of the year and at different hours of the day, it was observed that the surface temperature is lower for the enveloped buildings than for the non-enveloped, during the night but also during the day, less at lunchtime. This is due to the non-enveloped walls which heat up more slowly during the day than the enveloped walls, instead they store the heat and emit it during the day and especially at night where the temperature differences between the 2 types of buildings up to at 11°C.

Following the scenarios for enveloped and non-enveloped buildings, at different times, for August 1, the hottest clear day in Bucharest, in 2021, it was obtained that the air temperatures in the neighboring area of the enveloped buildings are lower, compared to those obtained from the scenario with non-enveloped buildings, both day and night, at several levels considered. The main differences (up to 0.9°C) being observed at 01:00 at the height of 20m in the proximity of the walls.

The results of the study show that enveloping buildings with new materials, when implemented in renovation projects or improving thermal efficiency, could reduce the effect of the island's urban heat.

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