Study of urban microclimate conditions in a commercial area of an urban centre and the environmental regeneration potential

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Abstract. Urban heat island (UHI) is a phenomenon that affects the urban microclimate. Land use, urban geometry, cover materials, vegetation, the water element and human activities are the most important factors that affect the UHI. This research focused on the study and analysis of the urban microclimate of three sections of a commercial street area that differ in their morphology. The first area includes a stream near the road, the second area includes the purely commercial part of the street and the third area includes the fringes of a hill in (Thessaloniki, “Toumpa”, Gr Lampraki Street). Using the Envimet V4 program, three simulations were performed for the selected study areas for the hottest day of the previous year, August 1, 2020. The values with the largest variations in all three areas were those of relative and specific humidity and finally air speed. The air temperature was higher in relation to the suburban area (UHI) and did not show significant differences in the three study areas. This leads us to the conclusion that the urban morphology, orientation and geographical location of the three study areas played the most important role in shaping the urban microclimate. Finally, is suggested one alternative scenario for optimizing the microclimate in the most burdened area of the three.

1. Introduction
Today, it is estimated that more than 50% of the world population lives in large urban centers and that percentage will reach up to 68% by the year 2050 [1]. Industrialization and urbanization have deeply impacted the structure and use of the land of modern cities, as well as their residents’ quality and way of life [1].

Modern cities are distinguished by small areas of greenery and large areas of impermeable materials [2]. The type of building structures (eg height, building materials, density) in combination with land uses are the primary factors that the climate in urban centers is completely different from that in the suburbs as well as in rural areas [2]. Therefore, the urban microclimate of an area is formed by the wider climatic zone to which the area belongs as well as by the anthropogenic characteristics of the area, morphological, building types, etc..

Intense urbanization and modern urban morphology have led to the rise of a phenomenon called “Urban Heat Island” (UHI). UHI is the reason behind the increased temperature in the center of the cities compared to suburban and rural areas, both during the summer and winter months [3]. Sangiorgio V. et al., 2020 [4], are trying to categorize the characteristics that affect UHI, which in turn burdens the urban microclimate in a worldwide scale. Having researched the various levels of UHI in 41 urban areas and 35 European cities, they came to the conclusion that the ability of the various surfaces in urban areas to reflect solar radiation affect the shaping of UHI by 29%. The presence of
green spaces affect the shaping of UHI by 21%, while the variables of the “canyon effect”, meaning the height of buildings, by 8%, the width of roads by 10% and their orientation by 9%. They deem that the heat produced by human activity as moderately significant in the shaping of UHI, while the population density affects it by 12%. The remaining parameters (e.g. meteorological variables) combined, reach up to 11% of influence.

Moreover, UHI acts like a “trap” for air pollution in urban centers, causing severe consequences both on a socioeconomically [5] and environmentally. Some of the results of UHI in urban areas include health problems, discomfort due to high temperatures, risen mortality due to intense heat and air pollution [6], greater need for air conditioning in the summer months and decreased need for heating during the winter [3],increased water consumption [7].

Especially for the town of Thessaloniki, the UHI affects the $T_{air}$ around 2.7- 4.0 °C between the urban centre and the suburbs [8]. Also according to A. Kantzioura et al. [8], 2012, the $T_{air}$ in central urban is higher than the suburbs especially in early morning hours. Furthermore, the sea breeze coming from two different circulation mechanisms (the Thessaloniki Bay cell during the morning hours and the stronger one of Thermaikos Gulf at mid-day) affects too the microclimate of the town of Thessaloniki [8].

2. Scope
The aim of this work is to investigate the environmental conditions in an urban road, among three areas with different urban morphology and to make new proposals for their environmental regeneration. Thus, for the investigation of urban microclimate factors, was selected an urban center with typical and also modern features with a Mediterranean climate (Lambraki Street, Thessaloniki). Through simulations and analysis of the results, identified a number of key factors which influence the most the urban microclimate in the urban centre. The resulting data from this research may be useful in future studies which may refer to the conditions-factors of shaping the urban microclimate in the urban center or in the environmental design in any city with similar climatic and morphological features.

3. Methodology – data – case studies

3.1. Methodology
The focus of this research is the study and evaluation of the urban microclimate conditions in a commercial area of the city of Thessaloniki, specifically in Gr. Lampraki high street which is located in Toumpa district. The conducting and comparison of the results is done with the use of the simulation software “Envi-met V4”. The research also deals with the deployment of these results for the environmental regeneration of the most burdened area of the three.

3.2. Data
The date chosen for the simulations in all three study areas is the 1st of August 2020 as according to meteo.gr (2021) was the hottest day of the year. According to the website the meteorological station which recorded the hourly values for this specific day is located in the airport at a distance of 13.8 km from the center of the city (suburbs).

It is indicative that on the 1st of August 2020 the temperature at 00.20 was 27°C, at 02.50 it was 25°C (lowest temperature of the day), 36°C at 15.50 (highest temperature of the year for Thessaloniki) and finally 26°C at 23.50. The relative humidity at 00.20 was at 51%, 39% at 13.20 (lowest value for the day, also recorded at 18.20), at 15.50 it was at 47% and at 23.50 it was at 70% (highest value of the day due to temporary rain which is typical for this season). The winds ranged from 1Bf to 4Bf (0.3m/s −< 1.6m/s to 5.5 m/s −<8.0m/s) and were mainly southeast and west.
3.3. Study areas

1st Study area
The first part of Gr. Lampraki to be studied is the point where the road crosses the stream (figure 1). The width of the road is 12.0 m and the sidewalk on each side is 2.50 m wide. The roads that intersect the main artery are approximately 5.00 m wide with narrow sidewalks of up to 1.50 m and without any greenery. The area surrounding the stream is rich in vegetation, especially tall deciduous trees. On both sides of the stream, building blocks are being developed with a predominant residential use. These are mainly four to six floors apartment buildings (years of construction 1970 to 1990) made of standard building materials. The bridge is made of cement with asphalt paving on the road section and concrete slabs on the sidewalks. Water is found in the stream mainly during periods of heavy rainfall.

The simulation for the first location, as mentioned before, is based on the data for the 1st of August 2020. For the first simulation the structural materials set for the buildings are bricks for the walls and reinforced concrete for the terraces. The material set for the road is asphalt and for the sidewalks “medium grey” pavement tiles. The chosen vegetation are trees of medium density, reaching up to 20 m and placed along the road and on the banks of the stream.

2nd Study area
The second part of the street under study is the one where most of the shops in the area are concentrated (figure 2). The buildings (years of construction 1970 to 1990), the road and the sidewalk are also of standard building materials. The apartment buildings have two to six floors and their height ranges from 6.00 m to 18.00 m. The trees on the sidewalks are deciduous and the distance between them ranges from 3.00 m to 4.00 m. The road is 13.00 m wide with sidewalk on each side. The width of the sidewalk is 3.00 m.

The simulation for the second location is also based on the data for the 1st of August 2020. The structural materials set for the second simulation are the same as the ones from the first. The trees chosen for vegetation are of medium density, reaching up to 20 m and are placed on the sidewalk as shown on figure 2.

3rd Study area
The third and final part of Gr. Lampraki that we study is where the road crosses a hill (figure 3). At this point on one side of the road we find the hill (+10.00 m approximately) on which there are developed building blocks. On the other side of the road (+0.00 m) there are also building blocks composed of apartment buildings with their height ranging from one to six floors (3.00 m to 18.00 m approximately). The buildings (built from 1970 to 1990) are of regular structural materials and mainly used for housing. The road (13.00 m wide) and the sidewalks (2.50 m wide) were also built using regular materials. The greenery on the hill is fairly rich in deciduous trees and tall grass while on the other side of the road there also are deciduous trees planted every 3.00 m to 5.00.

The simulation of the third location is based on the same data as the first two. The same materials were also set for the buildings the road and the sidewalks. For the vegetation we selected trees of medium density and height up to 25 m, placed on the hill and the sidewalks. We also selected grass reaching up to 50 cm., as shown in img.3. Finally, the apartment buildings on the hill where drawn at a level of +10.00 m.
Table 1. Outline description of the three study areas.

| Study area                  | Building height | Vegetation                          | Water element | Land uses                                         | Specific features                        |
|-----------------------------|-----------------|-------------------------------------|---------------|--------------------------------------------------|------------------------------------------|
| 1st Study area, “stream”    | 12m. to 18m.    | Intense, deciduous trees, ivy       | Yes, stream   | “Local center-neighborhood center”, house - retail | “Local center-neighborhood center”, house - retail |
| 2nd Study area, “local center” | 6m. to 18m.    | Sparse vegetation, linear on sidewalks (every 3m.-5m.) | No            | “Local center-neighborhood center”, retail, offices, schools, services | Greek typical central point of a large district |
| 3rd Study area, “hill”      | 3m. to 18m.    | Intense on one side, deciduous trees, weeds and linear on sidewalks | No            | “Local center-neighborhood center”, house - retail | Altitude difference - hill with vegetation at + 10.00m. from street level |

Table 2. Thermal properties of the materials used in the Envi met simulations.

| Materials          | Density (ρ), kg/m³ | Coefficient of thermal conductivity (λ), W/(m²°K) | Heat Capacity (cₚ), J/(kg*K) | Water vapor diffusion resistance coefficient (μ) |
|--------------------|--------------------|--------------------------------------------------|------------------------------|--------------------------------------------------|
|                    | Dry                | liquid                                          |                              |                                                  |
| Solid soil         | 1800               | 2,000                                           |                              |                                                  |
| Reinforced concrete| 2300               | 2,300                                           | 1000                         | 130                                              |
| Roof tiles         | 0,400              | 1,000                                           | 750                          |                                                  |
| Glass              | 2500               | 1,000                                           | 1000                         | 10-25                                            |
| Pavement tiles     | 2100               | 1,500                                           | 1000                         | 60                                               |
| Walls made of Bricks| 1200              | 0,490                                           | 1000                         | 10-25                                            |
| Asphalt rods       | 2300               | 0,900                                           | 920                          | 50000                                            | 50000                                    |

4. Results and discussion

Below follows the comparative analysis of the results produced by the study areas relating to the air temperature (Tₐ₀), relative humidity (RH) and the speed of wind (WS) on the 1st of August 2020.

In figure 4 we compile the results of the simulation for the Tₐ₀ of all three locations, as well as the given data for the relative temperature of the suburb (meteo.gr, 2021). We notice that from 01.20 to 07.20 the relative temperature in the area is relatively higher than the Tₐ₀ of the three locations of study. Later, from 07.20 to 00.20 (2nd of August) the Tₐ₀ in the suburb is quite lower and at 20.20 the temperature difference reaches its peak at 4.57°C. The conclusion drawn by this information is that UHI is responsible for the temperature difference since it traps the heat inside the urban areas resulting in higher temperatures for the duration of the day in study areas than in the suburb. Moreover, because of the urban morphology, the orientation and the geographical position of the locations of study, there does not occur adequate ventilation during the night and that preserves the temperature difference.

Comparing the Tₐ₀ of the three locations we notice that the differences between them are too small and mainly occur in the first hours of the day, from 00.20 to 6.20. Thus, we conclude that the temperatures are more or less the same, regardless of the urban morphology, the orientation and the geographical position of the three locations. Which means that the Tₐ₀ does not affect the shaping of the urban microclimate considerably and is not affected by it.
However, the opposite seems to happen concerning the relative humidity (RH) in the three study areas and the suburb. What we notice is that there is a great deviation in the RH data of the first study area compared to those of the other three areas. The existence of the stream seems to have impacted deeply the shaping of the RH in that particular part of the street. The RH data for the second and third location were about the same, consequently the difference in the geographical position of the first location seems to have affected the shaping of the RH greatly. Therefore, we conclude that the geographical position affects the shaping of the urban microclimate.

Comparing the diagrams of the three locations to that of the suburb we notice that, for the biggest part of the day, the RH of the suburb was lower than that of the urban area with two exceptions. The data of the RH for the suburb surpassed those of the locations “2” and “3” at 7.20 and between 11.20 and 15.20 they reached the same level. The relatively high humidity contributes to the rise of the air temperature through vapor that acts like greenhouse gas. Furthermore, the concentration of vapor in the air is affected by the speed, the orientation and the kind of wind blowing in each area, meaning that it is influenced by the quality of the city’s ventilation. That means that the urban morphology, the geographical position and the orientation contribute to the shaping of the RH data.

Finally, figure 6 shows the wind speed (WS) for the three study areas. Here we observe that the WS in the first location ranged from 3Bf to 4Bf (4.15m/s to 5.73m/s) with the lowest speed occurring between 10.20 and 20.20. The WS in the second location ranged from 3Bf to 4Bf (5.49m/s to 6.38m/s) demonstrating a steady rise. In the third location the WS was 3Bf (3.23m/s to 3.85m/s) with a small rise between 09.20 and 21.20.

What we notice at first is that the highest WS data were from the commercial area (2nd location), the part of the street with the highest building concentration and the greatest height of structures, characteristics that are connected to the “Canyon Effect”. In addition, the lowest data were from the point where the street’s orientation changes, namely in the third location. In that part of the street there is also a concentration of tall trees, like in the first location, which connect to the WS. Trees affect WS, they can function like natural windbreaks and they can be used in urban planning to contribute to the control of the wind’s flow.

From all the above, it becomes clear that the WS is influenced considerably by the urban morphology, the orientation and the geographical position. Therefore, the urban microclimate is directly affected by the urban morphology, the orientation and the geographical position.

5. Proposal for environmental regeneration in the 2nd study area

From the previous comparative analysis we are lead to the conclusion that the 2nd study area is the most burdened compared to the other two. In this one the occurring $T_{air}$ data during the day are the highest while the RH data are almost the same as the ones from the 3rd location. Finally, the $W_{max}$ makes its appearance in this location due to the “Canyon Effect”. The 2nd study area is therefore chosen for the environmental regeneration scenario.

In the new simulation we replace the existing paving tiles with “light grey toned” instead of “medium grey toned”, because of their reflecting nature (due to their lighter colour). We also replace the paving tiles in the courtyards of the apartment buildings with natural materials (e.g. soil), and we
add trees in the large courtyard of the building block (figure 3, bottom right). Lastly, roofing tiles are placed on the roofs of the apartment buildings.

Concerning the vegetation, the existing trees are replaced by highly abundant ones with height reaching up to 25.00m. Highly abundant trees of medium coverage are also added in the narrow streets with 3.00m to 4.00m spacing between them, their height reaching up to 25.00m.

In figure 7 we can see that from 00.30 to 11.30 the $T_{air}$ in this scenario is higher than the existing one (as concluded by the first simulation) with the greatest temperature difference being 2.81°C at 4.30. According to the scenario $T_{air}$ should be 31.18°C while under the existing circumstances it was 28.37°C. From 12.30 to 00.30 (2nd of August) the $T_{air}$ in the scenario is lower than the one in the existing circumstances, with the greatest difference being 1.73°C at 16.30 and the scenario’s $T_{air}$ being 40.81°C. We also notice that the $T_{air}$ has a smoother rising course and the $T_{air_{max}}$ reaches up to 41.17°C at 15.30, not reaching the highest relative temperature (42°C) of the suburb. The greenery contributes to the reduction of the heat absorbed by the urban environment (road, sidewalks) during the day, resulting in a noticeable drop in temperature.

As for the RH (figure 8) we notice its rise compared to the existing one until 18.30. This happens because of the increased vegetation and the phenomenon of transpiration. Transpiration is the phenomenon during which the water turns into vapor via the flora’s pores and then evaporates. Transpiration is reduced when the water source decreases and completely stops during the night when the photosynthesis stops as well. Based on all the above, the rise of RH and its steady decrease after 18.30, compared to the existing readings, is justified.

In figure 9 we notice that the $WS_{max}$ in the scenario has averagely risen by 4.00m/s during the day. Also, based on the data on the diagram we conclude that WS in the scenario has a course parallel to that of the existing situation. The rise of the WS is caused by the height and the positioning of the trees in narrow vertical roads, characteristics that contribute to the “Canyon Effect”.

**Table 3.** Summary table of results for the three study areas and for the environmental regeneration proposal of the second study area.

|                | 1st Study area | 2nd Study area | 3rd Study area | Scenario for 2nd study area | Difference | Change rate |
|----------------|----------------|----------------|----------------|----------------------------|------------|-------------|
| $T_{air}$ (°C) | 42.74°         | 42.72°         | 42.19°         | 41.17°                     | 1.55       | 3.63%       |
| Max            |                |                |                |                            |            |             |
| Relative humidity (%) | 118.62% | 80.43% | 77.89% | 76.01% | 4.42 | 5.50% |
| Wind speed (m/s) (max) | 5.79m/s | 6.38m/s | 3.85m/s | 12.90m/s | -6.52 | 102.19% |
6. Conclusions
The goal of this study was the exploration of the mechanisms that shape the environmental conditions in a commercial part of Thessaloniki’s urban area. The results came from a series of simulations (and their analysis) in three neighbouring parts of a commercial road on the 1st of August 2020.

Through the research it was determined that:

- The $T_{air}$ in the urban area was higher than the one in the suburb through the day. This happens due to the phenomenon of UHI combined with the insufficient ventilation of the city during night time (because of the city’s urban morphology)
- The $T_{air}$ ranged in the same levels in all three areas without being affected by their urban morphology and their geographical position.
- The RH as well as the WS where affected by the geographical position, the urban morphology and the orientation of each of the locations.

So the factors that mostly influenced the shaping of the urban microclimate in these three study areas were their geographical position, their urban morphology and their orientation.

In the scenario of the second location’s environmental regeneration the following were determined:

- Vegetation can contribute to the lowering of the $T_{air}$ in the urban area.
- Greenery increases the RH levels during the day.
- The increase in vegetation in accordance to its positioning can contribute to the control of the wind’s flow.

Conclusively we could say that even in case where no radical environmental regeneration can occur due to the existing urban morphology, the addition of vertical vegetation against the buildings’ faces, green roofs or even the replacement of small trees with bigger ones could positively contribute to the lessening of UHI and the improvement of the urban microclimate.

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