Microclimate profile and contribution of air conditioning to local heat island effects at the Aristotle University of Thessaloniki main campus

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Abstract. The Aristotle University of Thessaloniki (AUTh) main campus is characterized mainly by its building volume, the energy fluxes serving campus needs and resulting from campus operations, and the local climatic conditions. In an effort to investigate the effects of the existence and operation of the AUTh main campus to the local climate of the Greater Thessaloniki Area (GTA), we applied a heat island effect related methodology to identify its subareas that belong to specific urban climate zones. This identification was supported by meteorological observations that identified specific characteristics of the urban heat island effect within the campus. As a next step, we investigated the influence of the air conditioning (AC) operation in AUTh to the local climate. For doing so we firstly estimated the actual AC cooling power installed in the campus. Then we employed the cooling degree days method to identify the overall AC operational profile during the summer period. On this basis, we calculated the total volume of heated air produced by the external AC units in the campus. Overall, we were able to identify three climate zones within the AUTh campus, and to estimate that local heat production from AC can affect urban climate. These findings are among the first to quantify the impact of specific urban structures and operations (AUTh campus) to the local climate in the GTA. The results of our study can be used for planning interventions at the urban web aiming at leveraging the burden of campus operation to the microclimate of the city center. The method used in our paper can be applied to wider urban areas in order to identify microclimate profiles and local heat island effects.

1. Introduction

The radical reform of societies since the industrial revolution, has not only changed the way we think, but the way we conceive the changes that occur around us. For the first time in human history, urban population has surpassed rural population following the changes that have come with industrialization [1], while human activities are affecting climate at local as well as global scales. As a result, urban climate studies have emerged as an important part of environmental sciences.

This work is focusing on the microclimate profile of the Aristotle University of Thessaloniki (AUTh) main campus, the biggest urban subarea within the heart of the Thessaloniki city. All activities that take place in the AUTh campus have an impact in the surrounding environment, mainly due to air pollutant emissions that result from campus central heating and campus-related traffic, or due to hot air resulting from the use of air conditioning (AC) systems used for cooling purposes. The paper addresses the impacts of aforementioned operations to the local urban climate and therefore to people’s quality of life.

2. Materials and methods

2.1. Study area

The Greater Thessaloniki Area (GTA) is an urban agglomeration with more than 1,000,000 inhabitants located in the Central Macedonia region in the northern part of Greece. The city faces the sea to the south and southwest (Thermaikos Gulf), the Chortiatis Mountain to the southeast, and the Seich-Sou
forest to the northeast. The climate is of Mediterranean type with hot, dry summers and mild, wet winters [2]. Thessaloniki has been an urban centre for 2,500 years, but in the recent years, its sprawl has been accompanied by a decrease of green spaces. It is estimated that green spaces in the urban agglomeration of Thessaloniki are unequally dispersed, ranging from 0.8 m² per inhabitant (in the western districts) to 30.62 m² per inhabitant in the eastern, and having a mean of approximately 5 m² per inhabitant [3].

AUTh, located in the centre of the city of Thessaloniki, was founded in 1925 and is the second largest university in Greece, with approximately 70000 students and 2000 professors. University campus size is approximately 334000 m² [4], with a complex network of buildings and open spaces (figure 1).

![Figure 1. Map of the AUTh main campus](image)

2.2. Urban Heat Islands and Local Climate Zones (LCZs)
Climate change has emerged as one of the defining issues of the early 21st century. NASA’s Goddard Institute for Space Studies finds that global surface temperatures in the past decade are 0.8 °C higher than the start of the 20th century, with two thirds of this warming having occurred since 1975 [5]. Recent research has shown the effects of human activity on what can be described as climate change and can be recognized as the driving force of recent extreme weather conditions [6].

Urban environment is the subject of most of the scientific research that is dealing with climate change since modern cities are described as the defining climate phenomenon of 21st century, as urbanization is still progressing in the whole world [7]. The design of big metropolitan areas leads to the formation of unique climate conditions, which can be described as urban climate and affect parameters as temperature, precipitation, wind direction, etc. [8]. Urban Heat Islands are a particular example of urban climate influence: cities are warmer than rural areas, as a result of their complex topology and the thermal capacity of building volume.

2.2.1. Discrimination between rural and urban areas
An attempt to fully define the differences between rural and urban areas seems impossible as a result of the topology, physical structure of modern cities and thermal climate differences between nearby areas. In the heat island literature, the term urban evokes an eclectic mix of local settings from which its observations have originated [9]. In research, we defined the term urban as a densely populated area, which may have areas of trees or even free of structures land but is still considered to be part of the metropolitan area, in contrast to a rural area that is almost free of human activity.

2.2.2. Local Climate Zones
Through this initial discrimination, there have aroused different classifications concerning the classification of urban territory in various climate zones. We have applied the zoning system proposed by Stewart and Oke in 2012, where LCZs are defined as “regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers on horizontal scale”. On this basis, urban areas are divided in 17 different LCZs, as described in Table 1 [10].
2.2.3. Weather data
In order to justify the LCZ classification it is essential to examine temperature differences between various zones, a common strategy in urban climate studies [11]. A reasonable classification in different LCZs is supported by mathematical modeling and weather data, providing sufficient evidence to demonstrate the differences which indicate the need to divide urban space in various zones.

Table 1. Definitions for Local Climate Zones [11]

| LCZ  | Build types       | LCZ  | Land cover types            |
|------|-------------------|------|-----------------------------|
| LCZ 1 | Compact high-rise | LCZ A | Dense trees                 |
| LCZ 2 | Compact midrise   | LCZ B | Scattered trees             |
| LCZ 3 | Compact low rise  | LCZ C | Bush, scrub                 |
| LCZ 4 | Open high-rise    | LCZ D | Low plants                  |
| LCZ 5 | Open midrise      | LCZ E | Bare rock or paved          |
| LCZ 6 | Open low rise     | LCZ F | Bare soil or sand           |
| LCZ 7 | Spacerly built    | LCZ G | Water                       |
| LCZ 8 | Lightweight low-rise |   |                             |
| LCZ 9 | Large low-rise    |   |                             |
| LCZ 10| Heavy industry    |   |                             |

We firstly used data from the weather station located in Thessaloniki Airport (14 km south from city centre), in order to distinguish the difference between the urban heat island and the rural environment. As a next step, we used data from a monitoring station located in the south-eastern outskirts of the campus (attached to the 3rd of September street), while we also made use of data coming from a monitoring station located in the heart of the campus. We carefully selected recordings favorable in pronouncing possible diversification of the climate zones: clear sky and relative apnea (i.e. wind speed of less than 10 Km/h). We chose our recordings two hours after sunset, which was at about eight in the afternoon, so the measurements were taken at 22:00 local time (to minimize the impact of direct solar radiation yet without any night effect).

2.3. Microclimate and air thermal loads resulting from air conditioning systems

Many countries in the southeast basin of the Mediterranean, including Greece, have been experiencing the phenomenon and impact of climate change for several years, with warm and dry seasons being prolonged and wet seasons becoming shorter, making the use of air-conditioning in order to cool the interior of a building imperative.
The extend use of air conditioning systems, has negatively effects as far as microclimate is concerned, contributing to further increase in local air temperature. It is therefore necessary to study the impact of the use of air conditioners not only on the environment in general but also on the local climate specifically [12].

2.3.1. Cooling Degree Days method.
A popular method for urban climate studies, which is increasingly used to ascertain the dynamic relationship between energy consumption and outdoor temperature, is the method of Cooling Degree Days (CDDs). This method is simple, quick and can reliably estimate monthly or annual energy needs for cooling. Its implementation presupposes that the cooling is applied throughout the building, the indoor temperature of the building is kept constant and the air conditioning system operates for the whole summer period with a standard average rate of return [13]. A degree day can be defined as the difference between the temperature prevailing in the exterior of a building, from an indoor temperature, which is selected as the reference or base temperature [14].

Base temperature is selected as the temperature at which the building under consideration requires neither cooling nor heating to achieve thermal comfort. The method that provided with the most accurate results in the calculation of the CDDs was the one of the hourly temperature values, according to the following equation:

$$ CDD = \frac{\sum_{i=1}^{24} (T_i - T_{cb})}{24} \tag{1} $$

Where $T_i$ is the environment temperature outside the building, $T_{cb}$ is the reference temperature for the cooling days (both temperatures in °C), and $k$ represents the hours of the day.

The calculation of the warm air masses emitted by the campus due to the AC operation can be materialized if the cooling demand of the buildings is known, in order to use the ratio of annual energy consumption for cooling air conditioning purposes:

$$ Q_c = \frac{\dot{m} \times C_P \times ACDD \times 10}{COP} \tag{2} $$

Annual consumption is denoted by $Q_c$ and measured in KWh, and $\dot{m}$ depicts the air mass flow per second (kg·s⁻¹). Term ACDD represents the annual sum of Cooling Degree Days, while the number 10 corresponds to the number of hours that the building under study is considered operational. COP stands for Coefficient of Performance of the air conditioning unit used. Specific heat capacity of air ($C_p$) is 1.005 KJ/kg·K [15]. It has been assumed that half of the air conditioning units are operating in each case so in the equation was added a correction factor, $\omega = 0.5$.

2.3.2. Assumptions and estimates made for accurate results
The calculation of the warm air masses produced due to the AUTH campus air conditioning was based on the estimation of its cooling demand. For this purpose, we proceeded with a detailed estimation of the cooling demand of one of the (typical) buildings of the campus, and then used this as the basis for the overall campus cooling demand calculation (details are provided in Gavros, 2018 [16]). The calculations for the rest of the university buildings were based on the building used as a reference (Building D of Engineering Department).

2.4. Microclimate change
Average global temperature has increased by 0.8 °C over the past 130 years. The results are already visible in recent years. The precipitation patterns are changing globally, the "eternal" ice on the two poles of the Earth and the snow at the highest altitudes of the planet are melting and as a natural consequence, the global average sea level rises. Climate change is a phenomenon that threatens the very existence of cities, regions and in some cases even entire states [17].

In this particular work we processed the temperature data of the campus that we received from the meteorological station of the AUTH. These data were in form of five-minute measurements, which
were processed into daily averages. The aim was to produce a graph that reflects the evolution of daily average temperature in the AUTh campus over the last 25 years. Based on the shape of the curve which will result, we extracted an equation that provides a basic forecast of the temperature variation, for the next few 40 years. Results of this analysis may have an impact on the other results of the present case study, so we studied the effect of a possible rise or fall of daily temperature on this research results.

3. Results

3.1. Classification of university campus in different climate zones
The campus of Aristotle University of Thessaloniki was classified into three main climatic zones, as follows:
1) Open midrise: Buildings in this zone meet the limitation of floor elevation (no more than nine floors). Additionally, they are within a reasonable distance, considering the building density. There is scattered vegetation but not to such an extent as to justify the inclusion of the area in a different climate zone.
2) Compact midrise: Buildings classified in this LCZ are of average height since none of them exceeds nine floors and all have more than three floors. There is no satisfactory distance between the buildings belonging to this zone. Vegetation is almost absent in open spaces, which are mostly covered with cement, resulting in low soil permeability. The building materials of this zone include almost exclusively cement, bricks and stone.
3) Scattered trees: This area includes low vegetation and trees at such a density that it does not justify its characterization as dense. The soil is almost permeable, since it is covered by grass; the area is used by the university community as an open space for resting and recreation.

3.1.1. Classification of university campus in thematic maps in accordance to climatic zones
To clarify the logic of identifying three different urban climatic zones in the campus, it was necessary to portray them in thematic maps. The requirement for the LCZ classification was its extent, as well as its varying geomorphological, topographical and material composition. Figures 5, 6 and 7 visualize aforementioned zones.

![Figure 5. Scattered trees LCZ in AUTh campus](image)

![Figure 6. Open midrise LCZ in AUTh campus](image)

![Figure 7. Compact midrise LCZ in AUTh campus](image)

3.1.2. Verification of LCZ classification
It is necessary to consider the air temperature differences that justify zone diversification, to evaluate the choice of each selected LCZ as appropriate. Based on the preceding classification, it is expected that temperature observations within the campus area should demonstrate higher values than those originating from the airport area, as the latter is located away from the Thessaloniki urban heat island. Moreover, the meteorological observations station in the center of the campus is located in a LCZ with scattered trees and is therefore expected to report lower air temperatures in comparison to the station.
located in the south-eastern campus outskirts (3rd of September street, open midrise LCZ). Table 2 presents the relevant measurements verifying temperature-based LCZ differences.

Table 2. Air temperature in three different locations and in different dates

| Date     | Airport (°C) | Open midrise LCZ (AUTH campus center, in °C) | Scattered trees LCZ (AUTH campus outskirts, in °C) |
|----------|--------------|-----------------------------------------------|--------------------------------------------------|
| 3/4/18   | 13           | 16.21                                         | 13.88                                            |
| 4/4/18   | 13           | 16.03                                         | 14.51                                            |
| 10/4/18  | 14           | 18.52                                         | 15.69                                            |
| 11/4/18  | 14           | 16.84                                         | 15.29                                            |
| 13/4/18  | 17           | 19.76                                         | 17.41                                            |

Our findings suggest that air temperature readings within the urban thermal island are higher than those obtained by measurements conducted away from it. In addition, temperature readings coming from the two monitoring stations located in the center and in the outskirts of the campus demonstrate a remarkable difference of approximately 3 °C, with the lowest value apparently being recorded by the station located in the LCZ with scattered trees, as expected. Figure 8 visualizes the differences between air temperature of two LCZs within the AUTH campus and the temperature readings of the rural reference station located at the airport area. It also worthies noting that the relevant temperature difference between the two LCZ locations (both located in campus area) reaches a maximum value of 4.5 °C.

Figure 8. Temperature differences between two AUTH LCZs and from rural reference temperature

3.2. Aerial thermal loads abducted from university campus

3.2.1. Climate data analysis.

The fluctuation of temperature recorded in the AUTH campus through the year is presented in figure 9. It is evident that during the two summer months of July and August, the average temperature is 4 °C above the reference temperature set at 24 °C. Therefore, for this period of time, it is expected that there will be a greater need to use air conditioning systems for achieving better indoor thermal comfort conditions.
3.2.2. Results of the Cooling Degree Day Method

The distribution of cooling degrees days throughout the year demonstrates a pattern underlining the importance of the summer period: the month with the highest number of CDD is July, followed by August. On the other hand, October and April are the months demonstrating the smaller cooling needs, as the sum of cooling rates for these two months tends to zero. On the basis of these findings, we conducted an analysis that focused on the remaining five months (May, June, July, August, September), where we consider that all of the cooling load is concentrated. Interestingly, September has a much higher sum of CDDs compared to May (cooling rates almost five times higher) while it worthies noting that the breakdown of grades is concentrated exclusively in the first twenty days of September.

Table 3. Sum of CDDs for each month for summer season of year 2018

| Month     | Monthly Cooling Days |
|-----------|----------------------|
| April     | 0.63                 |
| May       | 4.68                 |
| June      | 45.75                |
| July      | 82.41                |
| August    | 63.20                |
| September | 24.49                |
| October   | 0.00                 |

We calculated the hot air outflow from the air conditioning systems and for the building of reference in the AUTh campus, being equal to 169.41 kg/s. By applying an appropriate conversion [18] the resulting volumetric flow becomes equal to 203.29 m³/s and taking into account the volumetric characteristics of the building under investigation, the hourly warm air “production” is estimated around 700000 m³/hr. On the basis of this calculation, we estimated the aerial thermal loads abducted from AUTh buildings (Table 4). It is evident that the amount of warm air produced is proportional to the overall building volume.

Table 4. Aerial thermal loads abducted from AUTh buildings

| Building                                | Air flow per second (m³/sec) | Air flow per hour (m³/hr) |
|-----------------------------------------|------------------------------|---------------------------|
| Faculty of Education                    | 1.8                          | 6578                      |
| Faculty of Sciences                     | 226.3                        | 814825                    |
| School of Biology                       | 232.0                        | 835276                    |
| Faculty of Philosophy (Old Building)    | 150.9                        | 543311                    |
| AUTh Library                            | 8.3                          | 29890                     |
| School of Medicine                      | 73.3                         | 263941                    |

Figure 9. Annual variance of daily $T_{\text{mean}}$ (8/2017 – 8/2018)
3.3. Microclimate change impact

Thessaloniki is expected to experience an increase in high temperature days and days with high cooling demand on the basis of related scenarios [19]. According to air temperature data of the past 25 years (figure 10), there is a slight increase of average temperature per year (expressed in eq. 3, where $T_{av}$ depicts the daily average temperature and $x$ denotes the date in numerical form).

$$T_{av} = 7 \cdot 10^{-5}x + 13.993$$  \hspace{1cm} (3)

Figure 10. Temperature variation in the time period between 1992 - 2017

Such results, if projected in future time, suggest an increase in the average temperatures of the next 40 years which of course has an impact on the research findings reported above: annual cooling days are expected to increase (table 5) and because of this, thermal load resulting from university campus will also raise (table 6).

| Table 5. Estimated sum of CDDs for different future years |
|----------------------------------------------------------|
| Year | Average annual Temperature ($^\circ$C) | Sum of CDDs |
|------|---------------------------------------|-------------|
| 2017 | 17.01 | 221.17 |
| 2027 | 17.26 | 251.87 |
| 2037 | 17.52 | 284.93 |
| 2047 | 17.77 | 317.42 |
| 2057 | 18.03 | 352.03 |

Thermal aerial loads from university buildings will also raise as a result of the temperature increase (the influence of climate change on this part of research is presented in table 6). Considering the urban climate zone classification, climate change seems to have no impact.

| Table 6. Estimated aerial thermal loads abducted from AUTh due to CDD increase in the future |
|------------------------------------------------------------------------------------------|
| Building | Air flow per hour (m$^3$/hr) - | Air flow per hour (m$^3$/hr) - | Air flow per hour (m$^3$/hr) - | Air flow per hour (m$^3$/hr) - |
|          | 2027 | 2037 | 2047 | 2057 |
| Building D | 735825 | 738503 | 764898 | 781661 |
| Faculty of Education | 6613 | 6638 | 6875 | 7025 |
| Faculty of Sciences | 819242 | 822223 | 851610 | 870274 |
| School of Biology | 839804 | 842860 | 872985 | 892117 |
| AUTh Library | 23156 | 23241 | 24071 | 24599 |
| School of Medicine | 265372 | 266338 | 275857 | 281902 |
4. Discussion

The identification of three different LCZs within the AUTh central campus is considered reliable, as climatic data verifies the classification initially based on urban morphology observations. The classification is verified taking into account the air temperature values in the local climate zone of compact midrise, which were found to be slightly higher in comparison to the ones of the open midrise LCZ and in any case higher than those of the scattered trees LCZ. The conclusions resulting from this research are in agreement with similar studies [20, 21], which also point out the temperature difference between separate Local Climate Zones.

The estimation of warm air produced by the operation of air conditioning within the campus was based on the CDD method and resulted in a high-volume flow per hour of operation. Although it is not possible in the context of this study to evaluate whether such a volume flow contributes to further heating of the city center of Thessaloniki, we can suggest that based on these results the use of air conditioners at the Aristotle University of Thessaloniki, affects the microclimate of the campus to a certain extent. It is worth noting that this calculation involves a large margin of error because of the assumptions made, similarly to another relevant study for Greece [21]. Moreover, microclimate change seems to result in the raise of the thermal loads of buildings, as mean temperature increases through the years. Apparently, the microclimate of the city center will experience a non-negligible encumbrance, from the warm aerial masses resulting by the AC operation in the AUTh campus.

5. Conclusions

The local climatic conditions within the AUTh main campus were found to be reflected by three distinct LCZs. This categorization is supportive to similar urban climate studies related to the AUTh campus and to the Thessaloniki center in general. Moreover, our analysis revealed that the cooling-air conditioning needs of the campus buildings are elevated, as it has been shown by the sum of the cooling degree days. Therefore, it is obvious, compared to the recent past of the city that climatic conditions tend to change and it is now necessary to seek for methods of adapting the city to the climate profile that is being shaped in the area. For such a conclusion to be verified, more data are required.

Thermal loads resulting from air conditioners lead to a further increase of temperature in the city center where the university is located, especially during the hot days of the summer season, which makes the use of AC more imperative. Therefore, a ‘vicious circle’ is formed which obviously cannot be altered if there are no interventions aimed at reducing the urban heat island phenomenon, which creates and intensifies the specific problem. This problem can be addressed by interventions in the urban web of the city, with interventions like green areas and planted roofs on the terraces of apartment buildings.

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