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Monitoring Thermal Comfort in Outdoor Urban Spaces for Bioclimatic Conditions Improvem

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Abstract: This paper examines the microclimatic conditions and the feeling of thermal comfort in two different open spaces in the town of Drama, through constant record of the environmental parameters of temperature and relative humidity for a time period from 12/7 to 17/9/2006. Aim of the paper was to study the bioclimatic conditions of an open space, which was an urban park with vegetation and water, compared to an empty open central square space. Data analysis has proved that the average temperature was 2ºC lower in the park area. The improved temperature was noted in everyday basis, while during the warmer days the difference in temperature is bigger. During the 24-hours the biggest differences were observed during afternoon and evening hours. The relative humidity was about 4% higher in the park area and contributed to temperature decrease, since temperature and relative humidity follow opposite course during the 24-hours. Thom's Discomfort Index was also calculated and show that was lower at the park area in everyday basis and during the 24-hours, while the study of the rates shows that in most of the summer days and most of the day hours thermal comfort was ensured in this area. The Actual Sensation Vote (ASV) as for different sun conditions in the two areas was furthermore calculated and shows an improvement in thermal comfort at the park area in the order of 10 to 20%. Temperature starts to fall in the park area faster than in the central place and thermal comfort was more quickly achieved. The discomfort was expanded neither in the afternoon nor in the first evening hours, as it happens in the empty square. The aim of the essay is finally proved: vegetation and water contribute to the improvement of the bioclimatic conditions in the open spaces of the town.

Key-words: microclimatic condition, open space, thermal comfort, landscape design, greening, temperature.

1 Introduction

The existence of open spaces in the urban space assists the move of the aerial masses and the change of the air. The presence of natural formations of vegetation and water is determining the improvement of the microclimatic conditions in open spaces, as well as in the whole urban web in general, since they act as improving factors of thermal comfort, via shading, breathing, evaporation, and absorption of solar radiation [1, 2]. Microclimatic differentiations are presented even between neighbouring points of the same town because of its different characteristics, as it was proved by measurings in central London areas [3] and other European cities, such as Munich and Freiburg in Germany [4] and in Athens, Greece [5].

This paper studies the contribution of vegetation and water to the improvement of bioclimatic conditions in the open spaces of the towns, through environmental monitoring of temperature and of relative air humidity during summer days in two different open spaces in the town of Drama. To achieve this purpose these environmental monitoring were constantly recorded from 12/7 to 17/9/2006 using thermoigrografs in two selected open spaces.

The first open space was a park within the urban web, where the elements of vegetation and water are dominant, while the other one was a small central square, where 'hard' surfaces are dominant and there was hardly any vegetation. The recorded measurements were decoded, elaborated and valuated, in order to draw conclusions regarding the range of temperature and relative humidity at the two monitored points. Furthermore, via Thom's Discomfort Index (DI), thermal comfort and percentage of people who are expected to have feelings of discomfort at the open spaces were calculated as in past studies [6]. Finally, another indicator estimating thermal comfort at open spaces was calculated, named Heat Actual Sense Index ASV, which was developed within the framework of the European programme RUROS (Rediscovering the Urban Realm and Open Spaces) [7].

2 Methodology

2.1 Selection of measuring points of the environmental parameters

Two points were selected for the measuring of the environmental parameters of temperature and relative air humidity in the centre of Drama (Fig. 1). The selection of these points was based on the criterion of vegetation and water existence, so as to observe the influence of their presence or absence on the formation of the microclimate of the area.

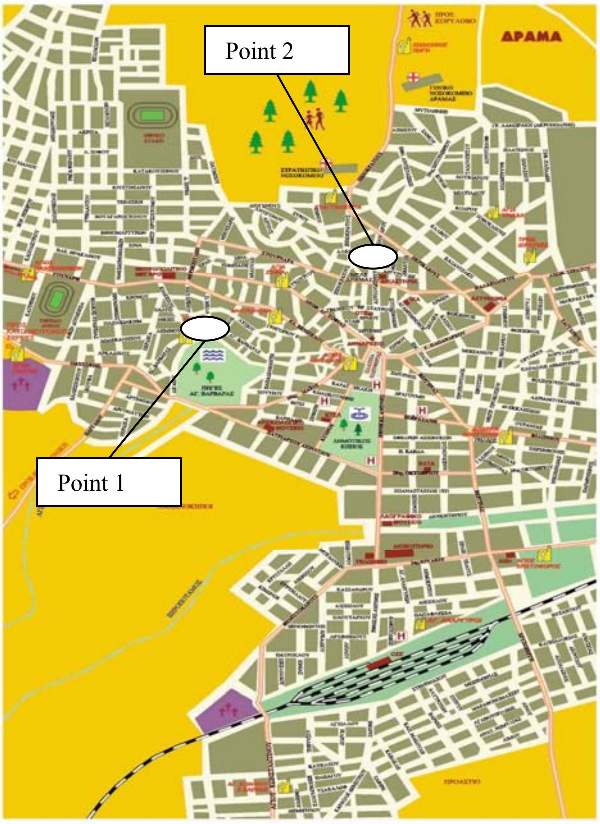

Fig. 1-Measuring points of the environmental parameters in the town of Drama

The first point is situated in St. Barbara's park, which is dominated by vegetation and big aquatic trees (plane-trees, poplar-trees) and water in the form of springs, brooks and lakes, while the surrounding area is encircled by multi-storey buildings and scheduled buildings, as well as roads with heavy traffic.

The second point is situated within the urban web, at a much frequented, central place of the town, which is the Dikastirion Square. This is a rather small, asphalted square, a part of which is used as parking place. The only existing vegetation is some ornamental trees and bushes planted on the grass around the place. The square boarders central busy roads. At the bottom of the square the court palace dominates. The surrounding area is densely built with multi-storey buildings.

2.2 Measuring instruments

For the measuring of the environmental parameters, thermoigrografs of type THERMOIGROGRAFO HT.1 were used, placed into meteorological cages. The cage at point 2 was placed in the shade of a small tree on the grass, so as to avoid the direct exposure to the solar radiation or the effect by a covering material having big thermocapacity.

2.3 Environmental parameters measuring methodology

The parameters of temperature and relative air humidity were constantly and on weekly basis recorded for the time period from 12/7/06 to 17/9/06. This particular period of summer months was selected, because then the climatic conditions are in favour of the feeling of thermal discomfort, so as to make obvious how the presence of water and vegetation have influence on these parameters and improve the discomfort feeling by improving the bioclimatic and microclimatic conditions in the open spaces.

The recorded measures of temperature and humidity have been decoded and recorded on tables per day and hour. With the help of these measures the Discomfort Index (DI) has been calculated by the relation (1) [1, 8]:

$$DI = TEM - 0.55(1-0.01HUM)(TEM - 14.5)\ ^{o}C$$

DI: Discomfort Index in ^{o}C
TEM: air temperature in ^{o}C
HUM: relative humidity in %

The average daily rates of temperature, relative humidity and discomfort index were calculated, as well as the average hourly rates, in order to elaborate and compare the results better.

The discomfort index rates were valuated based on table 1 which shows the discomfort that few, many or most of the people feel under particular temperature and humidity rates.

Table 1. Discomfort Index Rates (DI) in Celsius degrees and discomfort feeling range [6].

	Discomfort Feeling	DI ^{o}C
1	No discomfort	<21
2	Percentage <50% of the population displeased	21-24
3	Percentage >50% of the population displeased	24-27
4	Most of the population displeased	27-29
5	Everyone has a feeling of discomfort	29-32
6	Medical alert stages	>32

With the help of these measurements and with the climatic data concerning the town of Drama, the Heat Actual Sense Index ASV was calculated by using the model applied for the city of Thessaloniki, since the geographical co-ordinates of this city are the closest to those of Drama. For the calculation the following model has been used:

Thessaloniki ASV = 0.036 Tair_met + 0.0013 Sol_met – 0.038 V_met + 0.011 RH_met – 2.197 (r = 0.51) (2)

The ASV rates of the equations are inserted to the curves of Layout 1 and the percentage of users expected to feel comfortable was calculated.

3 Results valuation

According to the above elaboration of the measurements the following findings and valuations have been made concerning each one of the parameters: air temperature, relative air humidity and discomfort index.

3.1 Air temperature

At point 1 the average temperature is 22,8 ^oC, while at point 2 it is 24,8 ^oC, i.e. there is a difference in temperature between the central square and the park in the order of 2 ^oC. This difference lies inside the limits noted by other researchers in their essays [6,9,10]. At point 2 the average as well as the maximum daily temperature was always higher than at point 2.

During the warmer days bigger differences in temperature were observed between the two areas. These results were expected and are consistent with other researchers' results, such as Matzarakis [9] and Oke [11]. During the 24-hours temperature at point 2 was higher than at point 1. These results were consistent with other researchers' results [9]. The difference in temperature between the two areas was small during morning and early noon hours (8.00-15.00) and starts to increase noticeably after touching the maximum, so from then on it is held on higher levels during afternoon till the early morning hours (Fig. 2).

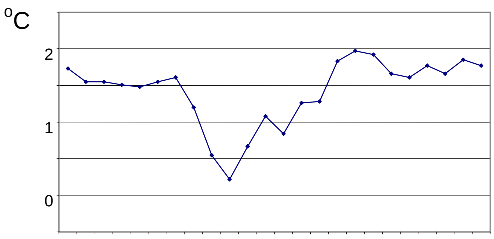

Fig. 2-Average differences in daily temperature between the two areas.

The comparison of the amassing diagrams and the corresponding histograms regarding temperature in the two areas shows that at point 1 temperature was under 26^{o}C to a percentage of 80% of the hours and hardly a 3% goes above 30^{o}C, while the respective percentages at point 2 are 65% and 15%.

3.2 Relative air humidity

The average relative humidity at point 1 was 73.16% and at point 2 69.5%. Humidity at the park area was increased by about 4%, due to the presence of dense vegetation and mostly to the presence of water. This difference was smaller than that of 7-14% referred as average difference by Theohari [12]. This was maybe due to the fact that the centre of Drama generally presents increased humidity rates, maybe because of the existence of springs and surface water at the Municipal Park and at St. Barbara's Park.

Most of the days the daily average humidity was at point 1 higher than at point 2, but there are also some days when humidity at point 2 was higher and particularly on 2/8, 3/8, 7/8, 10/8, 2/9, 3/9, 9/9 and 16/9. According to other researchers, [9,13] during the summer months humidity is increased in towns. One possible reason is that because of the high temperatures and the urban thermal islet phenomenon, the evaporation continues even during the night.

Temperature and humidity followed, as it was expected, opposite course during the 24-hours. So the more temperature increases the more humidity falls and vice versa (Fig 3).

During the 24-hours humidity at point 1 was higher after 2.00 p.m. till 9.00 a.m. when the difference was eliminated. After 9.00 a.m. and till 2.00 p.m. humidity was higher at point 2. The maximum difference of humidity between the two points was observed after 10.00 p.m. till the morning hours.

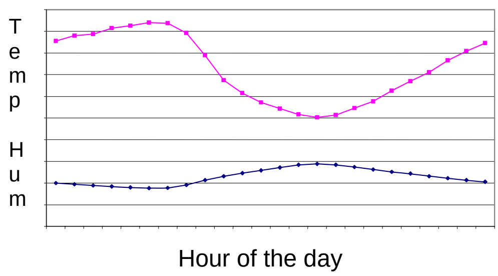

Fig. 3-Comparative depiction of the daily temperature and humidity range at St Barbara's Park.

3.3 Discomfort Index

The average and maximum Discomfort Index rate was in everyday basis higher at point 2 than point 1. The average Discomfort Index rate was during the whole 24-hours higher at point 2 than point 1. At both measuring points the highest Discomfort Index rate was observed parallel to the highest rate of air temperature (Fig. 4). So the highest Discomfort Index rate was observed at point 1 at 15.00 p.m. and at point 2 at 16.00 pm.

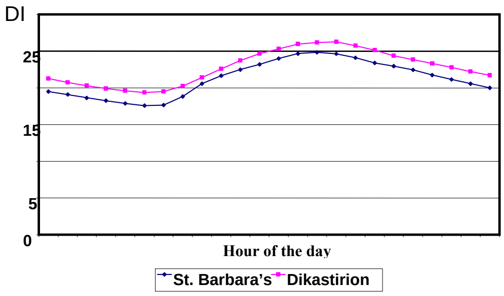

Fig. 4-Comparative depiction of average daily Discomfort Index range (DI) in the two study areas.

The difference in the Discomfort Index between the two areas does not fluctuate considerably during the 24-hours. This difference was smaller during the late morning hours, it increased considerably around 12.00 at noon and then it kept almost steady at the same levels till morning (Fig 5 and 6).

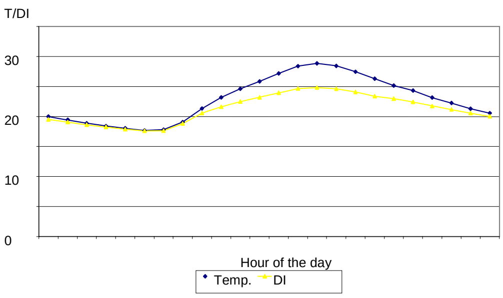

Fig. 5-St. Barbara's Park Comparative depiction of temperature and Discomfort Index daily course.

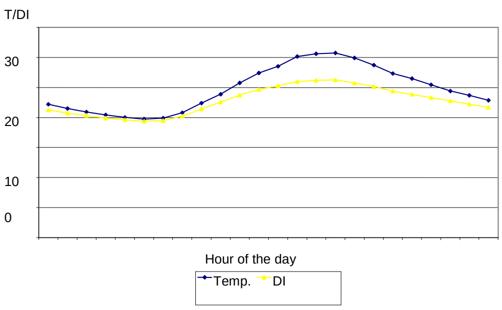

Fig. 6-St. Dikastirion Square Comparative depiction of temperature and Discomfort Index daily course.

The biggest differences in the Discomfort Index between the two areas appeared early in the afternoon from 3.00 p.m. to 6.00 p.m. (1.68°C), as well as just after midnight from 12.00 p.m. to 3.00 p.m. (1.69°C).

The study of the amassing diagrams and the corresponding histograms regarding the Discomfort Index (Fig. 6 and 7) lead up to the following conclusions: At point 1 the Discomfort Index was lower than 21°C and there was no discomfort feeling during the 50% of the hours, while at point 2 during the 40% approximately of the hours. At point 1 the Discomfort Index was lower than 24°C, so less than 50% of the population felt uncomfortable during the 90% approximately of the hours, while at point 2 only during nearly the 72% of the hours. During the whole hours of the day the discomfort index at point 1 was lower than 27°C, while at point 2 in 5% of the hours the index goes over 27°C and the discomfort feeling was strong so that most of the people felt uncomfortable.

The Discomfort Index daily course followed almost the same course with that of temperature. The higher temperature increased the Discomfort Index as well. The high Discomfort Index rate always lasted longer at measuring point 2 than at point 1.

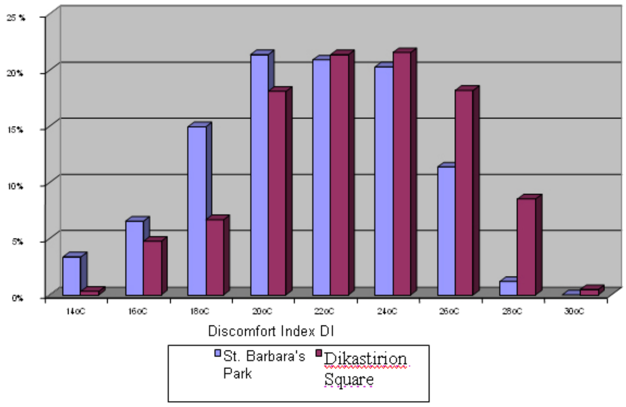

Fig. 6-Comparative depiction of the histograms regarding DI distribution related frequency % in the two areas.

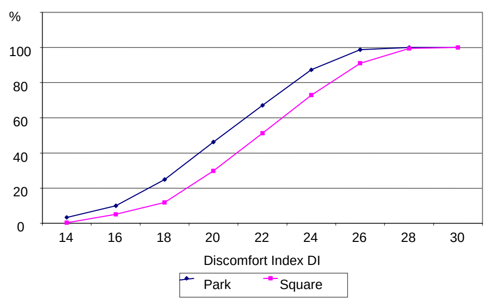

Fig. 7-Comparative depiction of the amassing diagrams regarding the fluctuation in the two areas.

Regarding the whole 66 days for which the measurements were taken from 12/7 to 16/9/06 and according to table 1, the observed situation as for the Discomfort Index was the following described in table 2.

Table 2. Discomfort Index and corresponding discomfort feeling in the two measuring points for the time period 12/7-16/9/06.

Discomfort Index DI ^oC	**Point 1**	**Point 2**
>24 ^{o}C (>50% of the population feels uncomfortable)	49 days	56 days
>27 ^{o}C (most of the population feel uncomfortable)	11 days	34 days
>29 ^{o}C (everyone feels uncomfortable)	6 days	0 days

3.4 Calculation of the Actual Sensation Vote

According to what Nikolopoulou et al. [7] mention at RUROS programme, the thermal comfort models as for the calculation of the Actual Sensation Vote (ASV) should be able to approach the microscale by distinguishing between sunned and shaded areas or areas protected and exposed to the wind, which finally affects directly the thermal comfort conditions at a given place. It is therefore important to find a method that enters parameters related to planning on the environmental data.

The assignment of simplified corrective factors between the locally measured conditions and those of the near meteorological station during the researches on the spot can reflect the change of the microclimate. Such corrective factors can be used as altering parameters for models of comfort examining the microclimate [7].

In this context, vegetation can influence microclimate in various ways, by reducing the air temperature compared to surfaces made of building materials, by shading and by protecting from the wind. As regards the presented models, such influences are probable to be included when it comes to valuation. At the urban place a reduction of the surrounding air temperature by 1-2^{o}C is expected due to a dense clump of trees, while the entering solar radiation can be reduced by 20-60% depending on the density of trees. Such numbers may be expected in the summer if the sky is clear, while any corrective factor should not be used if the weather is cloudy. Regarding the wind a factor of 0.4 can be used for the valuation of the wind speed reduction due to vegetation, which can be reduced to 0,2 in case that vegetation is used as windbreak.

Generally the steps to follow for the ASV calculation are:

• The geographical position appointment and the meteorological climatic data collection
• Definition of the town having the closest climatic similarity to the town under investigation or use of the European model
• ASV calculation for the corresponding town
• Reading, according to curves, the percentage of people feeling comfortable
• Enter designing parameters with corrective factors in order to calculate ASV at different places.
• Reading, according to curves, the percentage of people feeling comfortable
• Repetition of several steps

In order to estimate the Heat Actual Sense Index in the two areas of the research during the noon hours of the summer months the steps followed are:

• The thermal comfort model of Thessaloniki has been used, since the geographical longitude and latitude are closer to these of Drama.
• The ASV Index was calculated for noon hours and maximum solar radiation conditions (1000 W/m^2), for high sunning conditions, e.g. clear summer sky conditions (8000 W/m^2) and average sunning (400 W/m^2) e.g. partial cloudiness conditions [7].
• The temperature rate used was each time the maximum temperature of each area, according to the measurements taken for the time period 12/7-17/9/2006. So for the area of St. Barbara' s Park the temperature used was that at 15.00 and for the area of Dikastirion Square it was that at 16.00.
• The humidity rate used was the recorded humidity for the period 12/7-17/9/06 and it corresponds to the above temperature.
• The wind speed used was the average wind speed of July, August and September as it occurs from the meteorological data of Drama Tobacco Institute Meteorological Station.
• For the calculation of solar radiation and wind speed in the park area a corrective factor is used due to dense vegetation, according to the above mentioned [7]. So as regards solar radiation a reducing factor of 0.4 is used, while no corrective factor is used in case of cloudy sky. As regards wind speed the corrective factor used is that of 0.4.

According to the above and with the help of the curves of comfort of RUROS programme, the following results occurred, as these are concisely presented in the following table 4.

Based on these results we find out that in the park area there is an improvement of thermal comfort conditions during the summer noon hours considering the solar radiation conditions. The more intense the sunning is, the bigger the improvement is, due to the vegetation. In case of cloudiness no such influence exists. And since in Drama, as well as in all Greek towns the sunlight is dominant during the summer months, it is obvious that vegetation and water are necessary elements to the formation of the open spaces of the town.

4 Conclusions

From the preceded analysis of the results, it is clear that there is a microclimatic differentiation between the two measuring points (the park and the empty square), and this fact is consistent with other researchers' findings [4, 6, 10].

The microclimatic conditions were much more favourable at St. Barbara's park area than at Dikastirion Square area. The average temperature was by 2ºC lower during the summer months. The lowest temperature was observed everyday and in the warmest days the difference in temperature was bigger. During the 24-hours the biggest differences were observed during evening and night, as a result of the urban thermal islet phenomenon [4, 11].

Relative humidity is about 4% higher in the park area and that contributes to the fall of temperature, since temperature and humidity follow an opposite course during the day. Other researchers [12] found out an even bigger difference in relative humidity between the park and the square.

The Discomfort Index was lower in everyday basis and during the whole 24-hours at the park area and the study of its rates shows that in most of the summer days and most of the hours of the day, thermal comfort in this area is secured.

The Actual Sensation Vote (ASV), which was calculated for different sunning conditions, shows that at the park area thermal comfort was getting improved compared to the square, because of the presence of vegetation and water, which fluctuated from 10% to 20% approximately.

Temperature started to fall faster in the park area than in the centre of the town and thermal comfort is also more quickly achieved. Discomfort was neither expanded in the afternoon nor in the first evening hours, as it happens in the area of Dikastirion Square.

These favourable microclimatic conditions are due to the presence of vegetation and water in the town, as other researchers proved previusly [4, 5, 6, 9], since there was not any significant difference in other factors that could affect it, such as exposure of the measuring instruments to solar radiation, thinner and lower building, limited traffic etc.

On the basis of these remarks we lead up to the conclusion that vegetation and water should be the necessary elements to the formation of the urban open spaces, so that their bioclimatic conditions are improved and contribute to the general improvement of the aggravated urban microclimate.

In order to achieve that, it is advisable to augment those conditions, so that vegetation and water enrich the town of Drama, given that the town has always been connected to these two natural elements, which still exist, even to a smaller extent, both in urban and peripheral area.

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