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URBAN GEOMETRY PARAMETERS AS INDICATORS FOR URBANIZATION EFFECTS: A CASE STUDY IN PARANHOS, PORTUGAL

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Abstract

This urban climate study is about the parish of Paranhos – Porto, Portugal. The size of the parish area is approximately 7,2 km^2. The area grew substantially in the last fifty years both in terms of population number, widening of the urbanized area and extent of human activities as a result largely of the creation of a new University Pole. We have tried to evaluate the influence of the urban geometry of Paranhos as an external cause of the climatic subsystem, generating important contributions to changes in the behavior of temperature (thermal anomalies). The methodology is based on on statistical analyses of measured urban-rural temperature anomalies (ΔT_{u-r}) versus two parameters characterizing the urban structure, namely:

Street geometry is parameterized by a 2-dimensional view factor (*vf*) representing the unobscured angular fraction of sky in a vertical plane perpendicular to the street. This approach differs from the 3-dimensional sky view factor (Oke 1987).

Building density (*bd*) is parameterized by the number of buildings (n) in square areas of 100 × 100 m, (n/hm^2).

The correlations established separately between street geometry and building density respectively and the thermal deviations show that both parameters are of significance as explanatory factors for the urban heat island. The most densely built up areas with lowest *vf* correspond to the areas where the urban heat island is best developed and observed most often.

Keywords: Urban Environment, View Factor, Urban Canyon, Thermal Anomalies, Urban Heat Island.

1. Introduction

We are convinced that studies of urban climate can give good indicators of life quality and sustainability and can help to reduce/prevent situations of danger - or simply of lack of bioclimatic comfort - for the urban population.

Located on the NW coast of Portugal, Oporto is a medium-sized city with approximately 300 000 inhabitants, that has experienced an intense urbanization process, especially over the last 50 years. The town is integrated in the northwestern Atlantic façade of the Iberian Peninsula, in the occidental extremity of Europe, enclosed therefore in the zone of the mid-latitudes alternating and affected by the subpolar and subtropical pressure belts of the northern hemisphere, which clearly places it in the temperate latitudes.

The town of Oporto is situated on a platform down descending softly towards the Atlantic ocean. From the municipality of Paranhos the terrain also goes down almost imperceptible to the North, with altituds around 100/150 m.a.sl.

The area studied, the parish of Paranhos - Porto – Portugal, has grown substantially in the last fifty years, both in terms of population number, widening of the urbanized areas and human activities associated with the creation of a new University Pole.

The following steps were included in the process of data aquisition and analysis:

1.1 Collection and statistical analysis of data from stationary and mobile measurements of temperature in the parish of Paranhos;

1.2 Analysis of data from surface atmospheric pressure and temperature, relative humidity and wind;

1.3 Statistical/geostatistical comparison of collected data and data from the synoptic weather station at Porto-Pedras Rubras airport;

1.4 Measurements of the width of the streets and the building density (number of buildings/hm^2).

1.5 Statistical analysis of correlations between urban temperature anomalies and various possibly influential factors.

Realizing the importance of urban form and street geometry for the intensity of the urban heat island at street level (Oke, 1987 we intended to use the 3-dimensional sky view factor (*svf*), which gives the fraction of firmament that can be seen from a given point, to analyze the significance of the urban structure of Paranhos as an external cause of the climatic subsystem, generating important changes in temperatures (thermal anomalies), specially in constructed areas of great compactness. However, as explained below, it has not been possible to determine values of 3-dimensional sky view factors for the points of measurements. As a substitute, we have used a simplified, 2-dimensional view factor (*vf*) representing the unobscured fraction of sky in a vertical plane perpendicular to the street.

Several parameters were selected initially as possibly influencing the thermal behavior of the study area. Statistical correlations between the measured temperatures, the thermal anomalies and each of the selected parameters were examined. The two parameters found to have the highest influence on the urban temperature anomalies, in the area of narrow and old streets, are the view factor (*vf*) and the building density (number of buildings/hm^2, *bd*).

2.Methodology

2.1. Aquisition of data

Data for the study area were obtained from several sources.

Measurements of air temperature and relative humidity were made at 6 fixed sites. A passenger car was used for mobile measurements of temperature and relative humidity, using a digital termohygrometer installed in right side of the roof of the outside of the vehicle (at a height of around 1,5 m.a.g.).

The temperature of the Automatic Meteorological Station (EMA) of Porto-Pedras Rubras airport at the beginning of each run of measurements was taken as the reference for evaluating the urban temperature anomaly ΔT_{u-r}. Measurements were taken, during most runs, at a total of 100 points along a fixed route. The average duration of a run is appr.40 minutes, corresponding to an average time step between readings of appr. 25 seconds.

During every run repeated readings were taken at a 16 points of measurement along the route, selected to represent different urban environments.

Between November 2003 and January 2005 a total of 126 useful measurements (throughout 116 days) were performed, the majority of which during the night period and only six in daylight.

Synoptic charts from United Kingdom Meteorological Office, 00h00 and 18h00 as well as satellite NOAA 17 photos (Dundee Satellite Receiving Station, Dundee University, UK) have been collected. Whenever possible, the synoptic charts and the satellite photos corresponded to the hours next to the periods of measurement.

The synoptic charts and satellite photos have been used to obtain over the Porto region. Subsequently, the collected data were compared with the data from the synoptic airport station at Porto-Pedras Rubras. Later, going through the methodologies in the geostatistics domain, we proceeded to the analysis of the spatial structure of the information and its cartographic representation.

2.2. Data analysis

The following process was used for further data treatment and posterior cartography:

i) Local temporal trends at the 16 points, where repeated measurements were taken, were used for smoothing out local variations in temperature by means of linear interpolation. For each point (i) the time between the first and last reading is divided into n_i intervals and an adjusted temperature is calculated as

$$T\,adj_i = a_0 + a_1 * n_i \qquad (1)$$

ii) Denoting the over all change in temperature between the first and last adjusted temperature by δT and the corresponding number of time steps by N, we corrected all values to a time representing the midpoint of the run.

$$Tcorr_i = Tadj_i - \frac{\delta T}{N}\left(n_i - \frac{N}{2}\right) \qquad (2)$$

iii) The urban thermal anomalies were calculated relatively to the reference station:

$$(\Delta T_{u-r})_i = T\, corr_i - T\, ref \qquad (3)$$

With the purpose of converting the discrete information thus obtained into continuous data which is possible to georeferenciate, we applied the classic methodology in geostatistics, previously used in simmilar cases (J. Góis, 2004; A. Monteiro, and A. Fernandes, 1996): structural analysis, estimate with kriging and cartographic representation. The estimate of unknown values from known data, with kriging, implies the construction of variograms (a variogram consists of a mathematical function to evaluate the spatial continuity of a given variable, subsequently adjusted by theoretical models applied to the experimental variograms). The objective of the geostatistics is the study of the variability of spatially distributed data, his estimation and definition of vaguenesses and spatial representation of the variables (see illustration 1).

iv) The 2-dimensional "view factor" was calculated according to the following equation:

$$vf = (180 - (arctg\,(Hl\,/\,0.5W) + arctg\,(Hr\,/\,0.5W)))\,/\,180 \qquad (4)$$

where:

Hl (high left) is height of buildings to the left of the street (at measuring point i)

Hr (high right) is height of buildings to the right of the street (at measuring point i)

W (wide) is width of the street (at measuring point i)

Equation (4) refers to the central point of the street at a distance of 0,5 W from either side of the street. The heights of individual buildings along the streets and the width of the streets were obtained from the data provided by Oporto Municipal Council (Digital Mapping of Porto, the scale of 1:2 000). The value of *vf* should represent the screening from the different buildings that flank the street but, as we will see below, this is not always the case.

The two-dimensional view factor *vf* represents the concealment of the firmament, resulting from the perpendicular position of buildings on both sides of the street, but not all along the street, that is, the formula used here does not take into account the three-dimensional structure of the "urban canyon."

3. Results

The street data obtained from the Oporto Municipal Council were found not to portray accurately the real conditions because in certain cases there are high buildings that are not by side of the street but at some distance away. Such cases will distort the results. It was decided to use therefore not the official width of the streets, but to take into account the opening of spaces in certain areas where the buildings are not near the side of the street but very far apart from each other.

The factor building density (here represented by the number of buildings/hm^2) is a supplementary parameter representing the influence induced by the adjacent blocks and city areas, and therefore we can consider it as an influencing factor at the topoclimatic or local scale.

When examined by linear regression on data from individual runs of measurement the relation between the temperature anomaly and the parameters *vf* and *bd* respectively shows a considerable scatter (R^2-values typically 0,10 – 0,20). The intercepts a_i also vary considerably between different runs which may be seen as indicating shifts in general temperature level of the entire area of measurement relative to the level of the reference station. This illustrates the difficulty in finding a representative rural background temperature.

The mean value of the intercept a_{vf} (1,33) may tentatively be interpreted as representing approximately the upper limit of the *local* urban temperature anomaly. i.e. at $vf=0$, corresponding to a completely closed sky. The mean value of the intercept a_{bd} (0,97) may tentatively be interpreted as representing approximately the lower limit of the urban temperature anomaly, i.e. at $bd=0$, corresponding to the mean shift in temperature levels between the reference station and the *local* rural background level of the study area.

The slope of the regression lines is in qualitative agreement with the expected behaviour and approximately consistent around -0.45 for *vf* and 0.02 for *bd*. Thus, the *local* dependence of temperature on each of the two parameters may be fairly well established. Further analysis on larger amounts of data is needed, however, to verify the relevance of these results (see Table 1).

Regarding wind direction and wind speed, it was not possible to analyze the influence of these parameters at the fine scale due to lack of data. Regarding the direction of the streets, although this factor is in the table of the correlations factors, no statistical treatment could be undertaken because of the uncertainty in local wind direction at street level.

In further developments we believe that the application of different statistical techniques such as nonparametric statistics, directional statistics, multivariate statistics (factorial methods) or classical methods like Markov, spectral analysis and auto-correlation models applied to the climatic mobile data, may contribute to a better understanding of the spatial-temporal variability associated to the urban island phenomenon.

4. Discussion

4.1 Urban building density

Urban development results in the removal and/or covering of a significant part of the natural materials, as the vegetation, the rivers, and the ground, which is substituted by brick, hardened, asphalt, steel, glass, etc. The layout of the urban geometry means that the various directions of the streets embody different microclimates as a result of differences in exposure to the sun (different angles of incidence of sunlight) and different directions of wind.

The green areas disclose a typical influence, being usually cooler than the involving area, in the summer; and more mitigated than the remaining area, in the winter (this is inclusively valid for habitually cold areas, as the Roberto Frias Street, for example, whose points modify its thermal behavior being more pleasant, in the spring, when the trees along the street get leaves).

The correlation established between the buildings density and the thermal deviations show that the high building density contributes to the phenomenon of the urban heat island. The most densely occupied areas with lowest *vf* correspond to the areas where the urban heat island was identified most often and of highest magnitude.

4.2 The 2-dimensional view factor

Oke (1987) considers that the level of the urban canopy ("urban canopy layer") is characterized by great complexity due to the pronounced three-dimensional structure of the surface and the complex dynamics of the atmospheric processes in the layer below roof level. Understanding of the complex dynamics can be simplified by reducing studies to lesser units, as the "urban canyons". The "urban canyon" unit is characterized by long, uninterrupted walls of buildings adjacent to the street and by the ground between them (in general, the street), This approach would represent the interaction between the buildings together instead of treating these as isolated objects. However, due to lack of proper equipment for fish-eye photography but also due to the very irregular building geometries along the streets which conflicts with the idealized canyon geometry, we have not been able to work out proper 3-dimensional sky view factors.

Through the correlation between the values of the simplified *vf* calculation and the urban-rural thermal anomalies it is clear that the 2-dimensional view factor is capable of explaining some part of the urban influence on temperature conditions. The same is true for the correlation between the thermal deviations and the building density. Both parameters are seen to influence the phenomenon of the urban heat island.

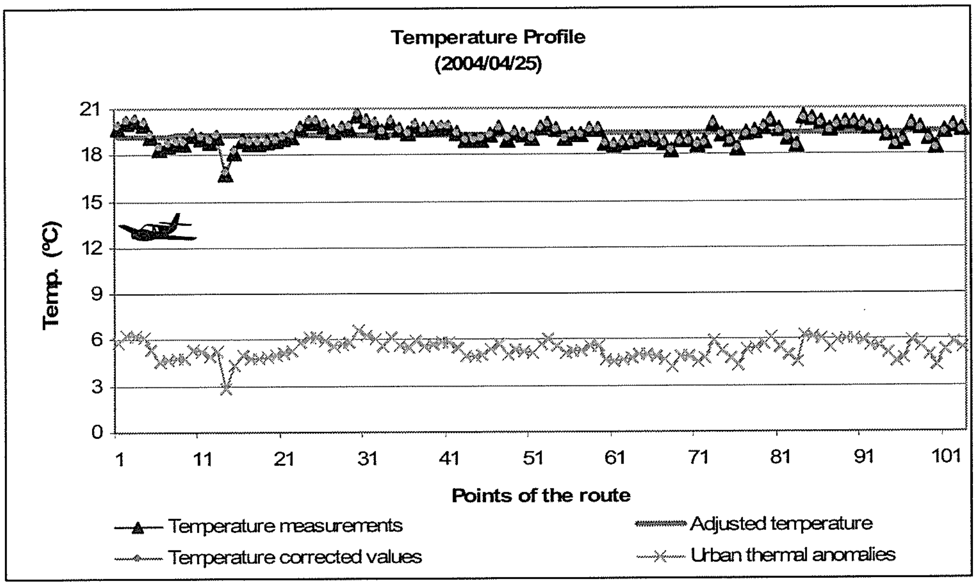

Fig. 1 - Evolution of the different temperature profiles along a fixed route.

Table 1.
Urban temperature anomaly vs. view facto
and building density (bd) respect
Linear regression on data from individual :

	dT vs vf		
Date	a_{vf}	b_{vf}	a
20031112	-0,06	-0,27	
20031116	-0,85	-0,20	
20031117	1,68	-0,40	
20031118	1,80	0,13	
20031119	0,52	-0,35	
20031120	-0,51	-0,16	
20031122	0,72	-0,11	
20031123	-1,12	-0,94	
20031124	1,76	-0,26	
20031125	-1,76	-0,09	
20031203	-0,09	-0,14	
20031204	0,86	-0,48	
20031209	1,01	-0,18	
20031210	0,93	0,06	
20031211	-0,06	0,06	
20031214	-1,03	-0,08	
20031215	0,67	-0,10	
20031216	2,47	-0,57	
20031217	-1,18	-0,15	
20031220	-1,66	0,04	
20031221	-1,23	-0,13	
20031222	1,89	-0,51	
20031223	-1,12	-0,94	
20031224	2,57	-0,18	
20031225A	2,60	-0,31	
20031225B	0,12	0,19	
20031226	-0,25	-0,13	
20040101	-0,10	-0,13	
20040102	0,68	-0,36	
20040103	0,44	-0,64	
20040104	1,89	-0,32	
20040105	-1,70	0,06	
20040106	-2,05	-0,04	
20040107	-0,54	0,04	
20040118	0,96	-0,30	
20040119	4,11	-1,28	
20040120	1,45	-0,38	
20040121	1,54	-0,45	
20040122	-0,44	0,02	
20040127	0,75	-0,19	
20040128	0,24	0,00	
20040202	0,71	0,21	

20040204	1,96	-0,55	1,29	0,03
20040205	0,26	-0,21	-0,02	0,01
20040207	3,37	-0,87	2,40	0,04
20040208	4,20	-0,22	3,87	0,02
20040209	0,15	-0,12	-0,03	0,01
20040210	3,03	-0,53	2,37	0,03
20040211	2,96	-0,43	2,45	0,02
20040212	2,74	-0,31	2,33	0,02
20040213	2,71	-0,35	2,23	0,02
20040214	2,57	-0,82	1,61	0,04
20040215	2,46	-0,35	2,01	0,02
20040216	0,69	-0,24	0,37	0,01
20040217	3,11	-0,24	2,75	0,02
20040218	5,26	-0,05	5,19	0,00
20040219	0,81	-0,72	-0,06	0,04
20040220	1,23	-1,21	-0,13	0,05
20040226	0,42	-0,31	0,05	0,01
20040301	4,85	-0,59	4,15	0,03
20040302	-1,02	0,15	-0,89	0,00
20040303	-1,01	-0,10	-1,15	0,01
20040304	1,01	-0,06	0,96	0,00
20040306	0,76	-0,21	0,51	0,01
20040314	2,67	-0,44	2,16	0,02
20040315	5,19	-0,73	4,37	0,03
20040316	3,15	-0,53	2,56	0,02
20040320	1,68	-0,13	1,51	0,01
20040321	0,54	-0,13	0,37	0,01
20040322	1,48	-0,28	1,11	0,02
20040325	0,43	-0,27	0,12	0,01
20040326	-0,41	-0,14	-0,59	0,01
20040327	0,13	-0,07	0,04	0,00
20040328	1,50	-0,27	1,20	0,01
20040403	1,29	-0,30	0,93	0,01
20040404	2,21	0,01	2,14	0,01
20040405	4,43	-0,93	3,37	0,04
20040406	3,28	-0,53	2,68	0,02
20040408	1,07	-0,15	0,86	0,01
20040412	2,24	-0,18	2,03	0,01
20040413	4,65	-1,08	3,43	0,05
20040424	4,29	-1,09	3,09	0,04
20040425	5,96	-1,01	4,80	0,04
20040426	4,47	-0,77	3,55	0,04

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