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MICROCLIMATIC VARIATIONS OF THERMAL COMFORT IN A LISBON CITY DISTRICT

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Abstract

A study of a new city district of Lisbon (Telheiras) was carried out to analyse the microclimatic influence of urban structures on bioclimatic conditions and create an empirical model to allow a generalisation of results to other places. The Physiological Equivalent Temperature was used for the assessment of thermal comfort in different microenvironments in the city district. Measurements of air temperature, short wave and long wave radiation were made and modelling was used to simulate wind speed and mean radiant temperature. A GIS was used to model spatial variations of PET, under different weather types.

Key words: Urban bioclimatology; PET; Lisbon

1. INTRODUCTION

The thermal component of the urban climate affects the quality of life in the city by its influence over the thermal comfort, health, performance, energy use and air quality (Jendritzky, 1993; Givoni, 1998; Santamouris, 2001; Matzarakis, Beckröege and Mayer, 1998; VDI, 1998). Within the framework of the CLIMLIS project[1], measurements were made in different scales in order to study bioclimatic conditions in Lisbon. As an example of the microclimatic influence of urban structures, the city district of Telheiras was selected.
Telheiras is a modern residential city district, built in the 1980s, in north Lisbon (figures 1 and 2). It is considered to be of high urban quality. The studied area is almost level and has altitudes of around 100 m. Buildings are mainly multi-familiar and their maximum height is around 25 m. The main streets have directions north-south and east-west and H/L ratios between 0.65 and 1.1. Courtyards are generally occupied by parking-lots, social amenities and green spaces.

2. METHODOLOGY

The work consisted of three parts:
2.1. Measurements of air temperature (Ta), long-wave (L) and short-wave (K) radiation. Two types of measurements were taken:

- Mobile measurements of Ta, K and L, in 5 days and 7 nights. Ta was measured with a digital termohygrometer, A1 Rotronic, K with a pyranometer CM 21 Kipp & Zonen and L with a pyrgeometer CG1 Kipp & Zonen.
- Ta measurements with a network of 10 fixed data-loggers (Tiny Talk, Geminy Data Loggers), in 10 places with different microenvironments (Fig. 2), in two periods of time (24 days in June and July 2001 and 10 days in February 2002); the data-loggers were placed in public lamp posts at a height of 3.5 m height above street level.

2.2. Calculation of Physiological Equivalent Temperature (PET - Mayer and Höppe, 1987; Höppe, 1993, 1999; Matzarakis, Mayer and Iziomon, 1999) was made with all the relevant parameters: air temperature (Ta), mean radiant temperature (Tmrt), wind speed (V) and vapour pressure (Pa), measured or modelled. PET is obtained through the full modelling of the energy balance of the human body, assuming a production of internal heat of 80 W/m^2 and clothing equivalent to 0.9 clo. As the results are expressed in degrees (°C), this model is very suitable for non-specialists. PET was calculated on any measurement places (fig 2) with the measured Ta. Tmrt was estimated with the model Rayman (Matzarakis, Rutz and Mayer, 1999) based on the astronomical and urban parameters as well as cloudiness. The results of the model were adjusted and validated through radiation measurements. The correlation coefficient between the observed and estimated Tmrt values was of 0.96 at night and 0.8 in the day. The V microclimatic variation was simulated by the Envi-Met model (Bruse, 1999) with wind in Lx/GC (Fig. 1) and the urban geometry was simulated; the Pa value used in this calculation was the same measured in Lx/GC.
2.3. Modelling of spatial variation of PET using an empirical model from the relation between that index and different atmospheric and geographic variables, what is done in two different phases:

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1. Modelling of the values of PET in Telheiras (dependent variable) using a stepwise multiple regression with independent variables divided in two groups: meteorological data (observed or estimated) in the meteorological station of Lx/GC, and parameters of urban morphology. In the first group of independent variables, measured Ta (Ta_{GC}) and cloudiness (NB_{GC}) were considered and global solar radiation estimated in the same place, after a model that was developed within the ongoing research of the author. The local variables are SVF and wind speed $V(t)$ estimated with the model Envi-Met. The SVF was calculated with the model Rayman. Values calculated with Rayman and with 23 Fish-Eye photos were compared (Fig. 3). There is a strong correlation between the two methods, subsequently the SVF values obtained by the Rayman model were considered suitable to use. Meteorological values in Lx/GC are the mesoclimatic background, in which local parameters introduce microclimatic variations.
2. Spatial interpolation of PET with the equation obtained in the previous phase, using a **GIS.** Independent variables are the different *Layers*. The interpolation was made within a grid with a side of 5m.

3. RESULTS AND DISCUSSION

3.1 Air Temperature

During the night, there is little spatial variation of Ta: the maximum average spatial differences were only 0.6ºC in winter and 0.8ºC in summer; Ta has a significant relation with SVF in summer (r^2 = 0.72), but not in winter (r^2 = 0.51). Highest night-time temperatures were almost always recorded on sites 3 and 5 (with low SVF – Fig. 4) and the lowest in the more open sites 9 and 10. During the day, thermal contrasts are greater (winter average 1.9ºC; summer 3.2ºC) due to the different exposition to direct solar radiation. Warmer places are near walls exposed to direct solar radiation (place 7 in the morning, place 5 in the afternoon, in summer). The relation between the obstruction of the horizon in different directions and Ta was analysed. In summer, there is a negative relation between Ta and the obstruction in the direction of the solar azimuth, and positive with the obstruction in the opposite direction.

3.2. Radiation

Tmrt was calculated from mobile measurements of K and L, according to Jendritzky and Nübler (1981) and VDI (1998). Night-time L and Tmrt presents a strong relation with SVF. It is much more complex in day-time. Early in the afternoon of 12 July 2001 (Fig. 5), measurements were taken in all the places under direct solar radiation except in place C, which was in the shade. In places in the sun, K↓ was the most important flux, while in place C the more important flux of K was from the north, due to reflection from a wall in that direction. The heating of the wall resulted in the L flux from that direction being also the most significant. Tmrt (Fig. 6) was higher in the more open places, with highest solar radiation (mainly fluxes from south and west) and with larger albedo (places E and G), consequently with larger K↑. K↑ is an energetic *input* on the human body, but it is energy that has not been absorbed by the surface, leading to a reduction of surface temperature and L↑; however, this reduction was not sufficient to make up for the increase of K↑.

3.3. Physiological Equivalent Temperature

PET has a much larger variation than Ta, depending on contrasts of Tmrt and v. The nigh-time average value of the maximum spatial differences of PET was 3.5ºC in summer and 3.9ºC in winter and has a negative relation with SVF (r^2= -0.79 in summer; r^2= -0.65 in winter). Places with highest values of PET was 3, 5, 7 and 1 (Fig. 4), with lower SVF and more shelter. By daytime, maximum average differences were 13.1ºC in summer and 8.9ºC in winter. Spatial contrasts depend mainly on radiative conditions, and, to a lesser extent, on wind speed.

3.4. Modelling of Physiological Equivalent Temperature

An empirical model was developed to estimate PET in Telheiras, when there was a lack of measured data and in order to generalise the calculation to other areas(Alcoforado, 1994, Andrade and Lopes, 1998, Svenson et al. 2002). Modelling of PET was conducted separately for nigh-time and day-time and in the case of the latter, for conditions in the shade and under direct solar radiation, in summer and winter. The R^2 values were between 0.93 and 0.98, which showed that the estimation allowed a good approximation to the measured values. The most important explicative variables were Ta_{CG} by night-time and on summer days and V(t) on winter days.

Continuous interpolation of PET in Telheiras was made under same typical conditions corresponding to different weather types. This allowed for the frequency of occurrence to be calculated for any one of the spatial patterns of PET. We present here two examples relative to night-time and day-time summer periods, with high temperatures, a cloudless sky and a weak wind rotating between north and east (direction of the estuary breeze). This weather-type frequency was about 11% in summer, in the period 1971-2000. The adopted reference period for the calculation was 15 July at 0h by night-time and 15h by day-time.

In the night-time situation (Fig. 7) the mesoscale base conditions in Lx/GC was Ta = 23ºC and northerly wind at 2.1 m/s. PET was over 18ºC in almost the whole area, only descending to under that value in the bordering open areas. The highest values of PET (> 23ºC) were estimated in sheltered places with low SVF. Although these values were calculated with clothing at 0.9 CLO, which may be considered a high value for a warm summer night (but which many people have for professional reasons, for instance). These kinds of conditions (which may occur, as previously seen, on 1/10 summer nights) undoubtedly cause discomfort, especially in relation to the need for nigh-time rest and the cooling of buildings.

By day, base conditions to the estimation of PET were Ta = 34.6ºC, easterly wind at 3.2 m/s, K = 877 W/m^2 and cloudless sky. PET was calculated separately in the shade and in sunny areas, identified by Envi-Met. On sunny and sheltered places, PET was between 55ºC - 58ºC (Fig. 8). Better ventilation reduces PET to 46.0º C- 49.0º C. In the shade, PET was between 30.0º C and 39.0º C, depending on the shelter.

CONCLUSION

The microclimatic study of Telheiras leads to the conclusion that spatial variation of Ta is small (on that scale). Bioclimatic differences depend, above all, on shelter and radiation conditions. The main factor that controls PET is urban geometry, because the area is very homogeneous with regard to vegetation and buildings and covering materials. Modelling of PET, by means of the described process, allows for the construction of very detailed maps, without local meteorological information, which can be a useful instrument in urban planning. The assessment of frequency of different thermal patterns can be made by considering the associated weather-types. The possibility of generalisation to other areas of Lisbon is a future work.

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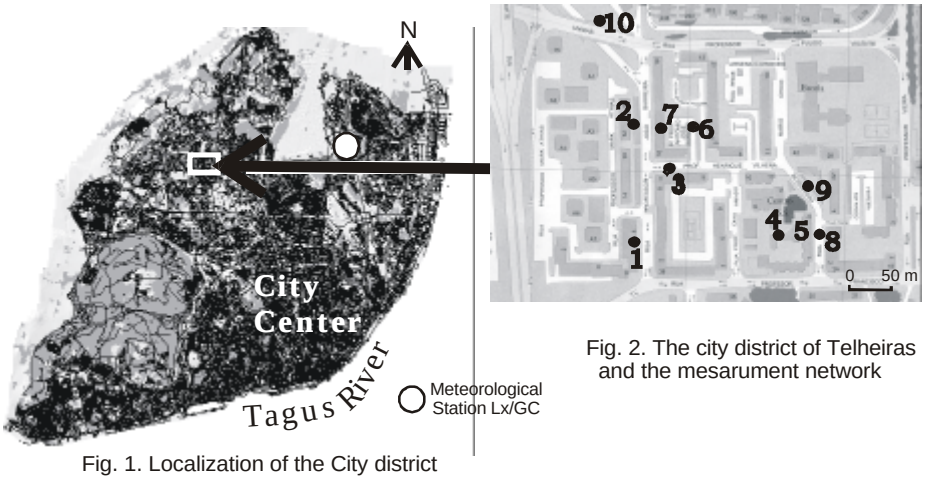

Fig. 1. Localization of the City district of Telheiras in Lisbon

Fig. 2. The city district of Telheiras and the mesarument network

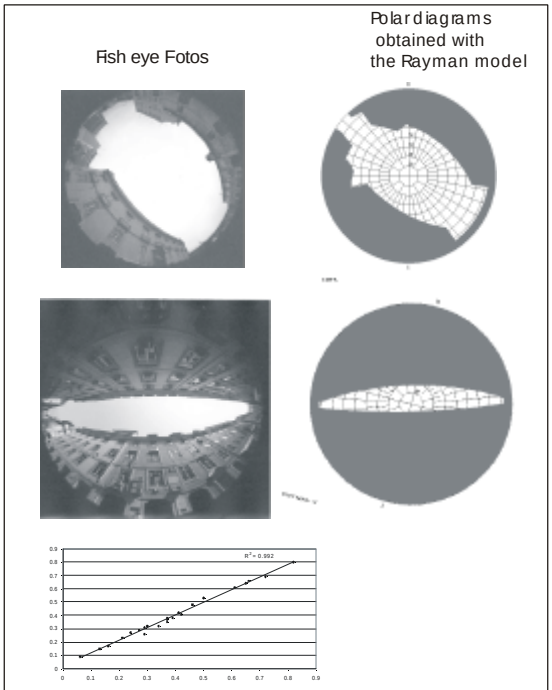

Fig. 3. Relation between SVF calculated with Fish Eye fotos and with the "Rayman" model

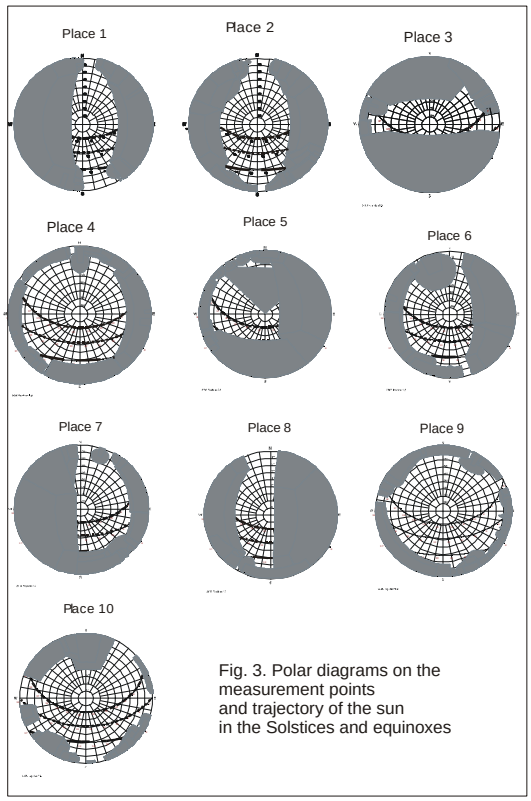

Fig. 3. Polar diagrams on the measurement points and trajectory of the sun in the Solstices and equinoxes

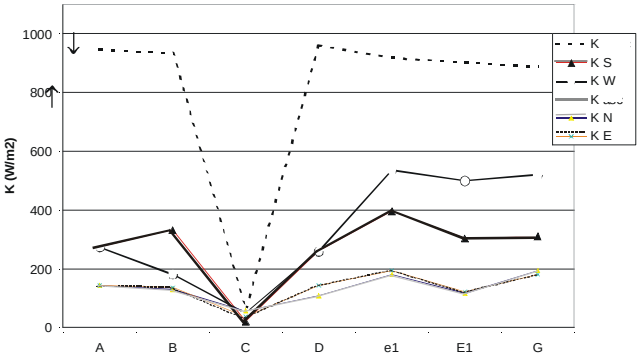

Fig. 5. Short-wave radiation measurements in 12 July 2001

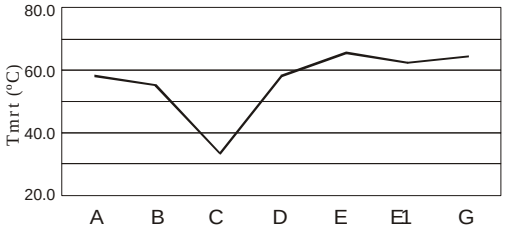

Fig. 7. Tmrt in 12 July 2001

Fig. 9.estimated PET (ºC) in a warm summer night (at 0 h), with cloudless sky and weak Northely wind

Fig. 8.Estimated PET (ºC) in a warm summer day (at 15 h), with cloudless sky and weak Easterly wind