

Application of climatic guidelines to urban planning The example of Lisbon (Portugal)

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ABSTRACT

In order to contribute to the sustainability of the urban environment, knowledge about the urban climate should be translated into climatic guidelines for planning. However, there are hardly any studies on applied urban climatology in areas with a Mediterranean type of climate. The study presented in this paper has several aims: to identify the climatic needs in a coastal city with Mediterranean climate; to describe the methodology, which can be adapted in order to be used in other cities; to discuss some of the problems that arise when applying climatic knowledge to urban planning, including the selection of the adequate scale of analysis, the required data and tools, the selection of the planning priorities, and the need to develop a shared language among planners and climatologists; and last to contribute to furthering the debate on the advantages of including climatic guidelines in Master Plans of urban municipalities in a systematic way. Lisbon's case study is presented. As planners need spatialized guidelines, the mapping of Lisbon's physical features was carried out using a Geographical Information System. Based on a Digital Terrain Model and on data of urban roughness a "ventilation map" was produced. A "building-density" map was also prepared based on the analysis of a Landsat image and field work. By cross-tabulating these two layers, a final map depicting Lisbon's "homogeneous climatic-response units" was prepared. Finally, a series of climatic guidelines for planning were put forth for the different units.

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1. Introduction

The proportion of the world population that lives in urban areas is increasing at a growing pace. In order to ensure urban sustainability, it is necessary to increase quality of life of the citizens, and to reduce the cities' impact upon the resources outside the urban space (Paccione, 2003; Steemers, 2003).

Among the urban environmental problems, the climatic features are particularly significant. The most evident examples of "inadvertent climate modification" (Oke, 1987) introduced by mankind are to be found in urban areas. In densely populated areas, changes in the wind flow, energy balance, temperature, humidity, precipitation, among others, are to be expected. In the context of global warming, particular attention has been given in the literature to the canopy layer urban heat island (UHI), i.e. the fact that the air in the urban canopy is usually warmer than that in the surrounding countryside (Oke, 1987), even though the scales of the two phenomena obviously differ. Although some physical features of the cities are

regulated by law (air quality, noise, etc.), there is no legal framework in place to ensure the achievement of a high-quality urban climate. Bitan (1992) has provided an example of a hypothetical city in which the air pollution levels never exceed the permitted thresholds, but where the quality of the climate is so low (too intense UHI, poor ventilation, etc.) that it affects the activities of the population, the comfort level and even the health of the city dwellers. An indirect but very important consequence of the UHI and of poor ventilation conditions is the increase in energy consumption associated with the cooling of indoor air, especially whenever the urban design and architecture are not bioclimatically oriented (Szokolay, 1997; Givoni, 1998; Tzikopoulos et al., 2005).

Although the characteristics of the urban climate have been known for a long time, there has been very little application of climate knowledge in urban planning (Oke, 1984, 2006; Eliasson, 2000; Mills, 2006). The first studies on applied urban climatology have been conducted in Germany in the 1960s and 1970s (Matzarakis, 2005), although non-applied research on local and urban climatology had been on-going since the first decades of the 20th century (Kratzer, 1937). In the 1980s, the Municipality of the Ruhr Area, well-known for its urban conurbations, ordered a systematic investigation on urban climate, as populations grew and urban density kept increasing, in order to achieve sufficient air and climate quality for the inhabitants (Stock and Beckröge,

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1985; Stock, 1992). In the resulting documents “climate analysis maps” and “synthetic functions maps” were included as well as reports with climatic guidelines for urban planning. In Switzerland, similar research projects have been carried out (Scherer et al., 1999; Fehrenbach et al., 2001; Thommes et al., 2001). Later on, the *Climate Booklet for Urban Development* was published by the German Interior Ministry of Baden – Württemberg (Baumüller et al., 2005). It proved to be a very useful tool for both scientists and planners, as it provides climatic guidelines for zoning and planning. “Stuttgart21” (Baumüller, 2005) and the “Berlin Digital Environmental Atlas” (Berlin Department for Urban Development, 2004) are two other big research projects, that have been used as examples.

Similar studies for southern Europe are almost inexistent. In Portugal, the analysis of 15 Master Plans of urban municipalities showed that although climatic or meteorological information was included in 86% of the cases (Alcoforado and Vieira, 2004), the reliance on climatic information never proved particularly useful. The main reasons for this fact are: the meteorological data from “classical” meteorological stations, such as those used in the Master Plans, are by definition inappropriate for the study of the climate at the urban scale (meso and microscale); in 90% of the cases, data with only mean values were included (total annual precipitation, mean temperature); the Master Plans hardly ever included any climate maps and, whenever they did, their scale was inappropriate for direct application. An additional reason seems to be the lack of knowledge by the authors of the Master Plans with regard to the features of the urban climate and to the ways in which the latter can be modified in order to improve the quality of life. Over the last two decades, research on the Lisbon urban climate has been carried out (Alcoforado, 1992; Andrade, 2003; Lopes, 2003; Alcoforado and Andrade, 2006; Alcoforado et al., 2006; Vasconcelos and Lopes, 2006). At the present stage, it has been considered necessary to

inform urban planners of the benefits of using climatic information and to translate the results of pre-existing studies into applicable climatic guidelines for urban planning.

This research was initially carried out within the scope of an applied urban climatology project, where one of the goals was to foresee the changes that would result from the process of urbanisation. As the City Council became interested in the research, another project was then set up with the aim of suggesting ways of reducing the negative local climatic effects of urbanisation. The results were translated into a series of guidelines for planning, which were compiled in a guide booklet and presented in cartographic form, not only for the city as a whole (mesoscale), but also for a particular city district in northern Lisbon (microscale). This paper focuses on the research carried out at the city scale. In the next section, the study area is briefly depicted and the methodology used in the delimitation of climatic units for planning purposes is described. The guidelines are presented in Section 3, followed by a discussion of the main aspects that should be borne in mind when carrying out research on applied urban climatology.

2. Materials and methods

2.1. Study area

Lisbon is located near the western coast of Portugal, at 38°43' latitude N and 9° 9' longitude W. The city lies 30 km to the east of the Atlantic shore and right on the bank of the Tagus estuary, which is 15 km wide eastwards from Lisbon (Fig. 1). The city covers an area of 84 km² and has circa 600,000 inhabitants. In the urbanized area, the altitude is lower than 160 m, although the topography is highly differentiated (Fig. 5): four main valleys run from north to south in the southernmost part of Lisbon; in the northern part of the city, a plateau gently slopes to the south. To the west, the Monsanto hill



Fig. 1. Location maps; 1 – traditional centre, 2 – Avenidas Novas (new centrality area), 3 – Monsanto hill, 4 – Lisboa/Geofisico Meteorological station; 5 – airport, 6 and 7 – measurement points.

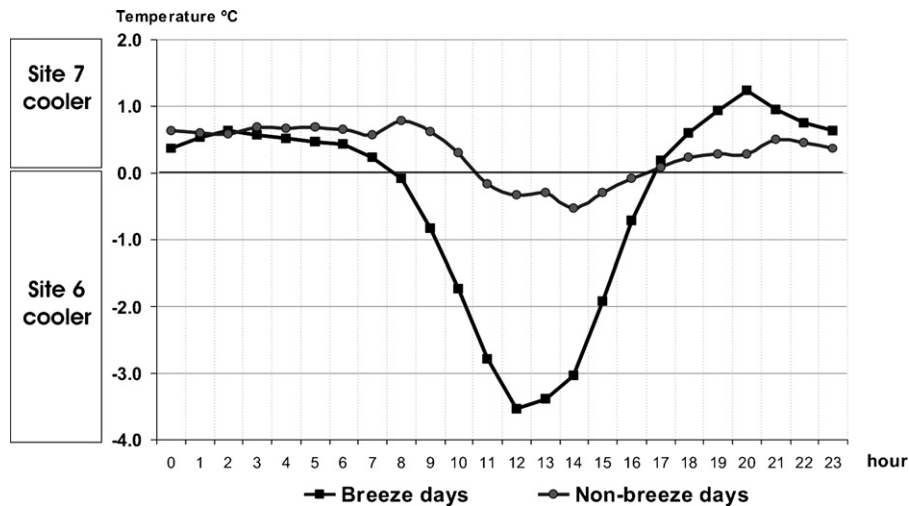


Fig. 2. Comparison of breeze and non-breeze days: air temperature differences (hourly average) between the Tagus Bank (site 6 in Fig. 1) and an inland measurement point (site 7) (June, July and August 2004; Vasconcelos and Lopes, 2006).

(a wood area identified by number 3 in Fig. 1) reaches a height of 200 m. The traditional centre is located near the river (1, Fig. 1), whereas the new centrality area (Avenidas Novas) is expanding northwards (2, Fig. 1).

Lisbon has a “Mediterranean” climate. N and NW winds prevail on a yearly basis, although there is large seasonal variability: winds blow mostly from the N, NE and SW (or W) in the winter, but from March onwards there is a significant increase in the frequency of NW and N winds. In the summer, N and NW winds occur on 40% of the days for 24 h a day and, on an additional 30%, only in the late afternoon (Alcoforado et al., 2006). This means that the prevailing N and NW winds are so frequent that they must be taken into account in planning and building design. The importance of considering ventilation conditions increases if we consider that Lisbon has become a rather polluted city, and very high levels of particulate matter have been recently recorded in the city centre.

On the other hand, when weak regional winds occur (speed under 4 m/s, Vasconcelos and Lopes, 2006), ocean and estuary breezes reach the neighbourhoods closer to the river Tagus on 30% of the late mornings and early summer afternoons, before the wind veers to the North in late afternoons and evenings (Alcoforado, 1992; Lopes, 2003). Even though they do not travel very far inland, the estuarine breezes play an important role in cooling the urban air near the river bank, where air temperature may be up to 4 °C lower than the city centre (Fig. 2).

The Lisbon UHI has an average intensity of 3 °C: the highest air temperatures occur mostly in the more densely built-up areas near the Tagus river bank and along the main circulation axis where urban development is under way. Under prevailing North or Northwest wind conditions, the core of the UHI is situated in the downtown areas (1, Fig. 1). In the presence of weak regional wind and estuarine breezes, the core of the UHI moves to the North (2, Fig. 1) and the downtown area remains relatively cooler. As human beings perceive the combined influence of the atmospheric elements, the bioclimatic conditions were assessed by computing a thermophysiological index, the Physiological Equivalent Temperature (PET–Höppe, 1999; Matzarakis et al., 1999), which took into account measured air temperature, atmospheric moisture, modelled wind speed (based on altitude and urban roughness, using the mesoscale simulation model WASP, Mortensen et al., 1993), as well as mean radiant temperature (using Rayman program, Matzarakis et al., 2007 – and subsequently following a procedure similar to that

described by Andrade and Alcoforado, 2008 to calibrate and validate the results). Discussion on the adequacy of the use of PET for the study of the bioclimatic conditions of Lisbon and subsequent validation of the model used there were made by Andrade and Alcoforado (2008). Both in the winter and in the summer, mesoscale variation of PET is similar to that of the air temperature, with the highest values occurring in the city core (associated with higher air temperature and lower wind speed) and the lowest values in the outskirts. The mean difference in the PET between the downtown area (1, 2 and 4, Fig. 1) and the outskirts is of 3.6 °C (Andrade, 2003), with a 10th percentile value of 2.7 °C and a 90th percentile value as high as 4.3 °C. In the peripheral areas, the wind speed contributes in a significant way to lowering the values of the PET. The lowest night time PET values in the winter (between 0 °C and 4 °C) occur in the outskirts of the city. In the summer daytime, under weak regional wind, PET values above 41 °C may occur in the downtown area, while the outskirts remain 3 °C cooler; as mentioned above, the influence of the Tagus/Ocean breezes considerably lowers the air temperature and the PET in the areas closest to the river.

2.2. Methodology for the delimitation of climatic units for planning purposes

Feedback from city planners and the experience of different authors working on the same topics (quoted in the Introduction), made it obvious that climatic guidelines can only be of use if they refer to areas whose limits are very precisely drawn on a detailed map.

A cartographical representation of Lisbon’s physical features had to be carried out, as existing land-use categories were not suitable, as these are mainly based on functional criteria. As a consequence, different types of land use may be included in the same functional class. Two different types of residential areas, for example villas and modern apartment towers, will interact in a very different way with the atmosphere and will give rise to different urban climates. Therefore the cartography considered useful for climatic purposes was based on the parameters more important to the urban climate: the topography and the land cover, considering mainly the built density. Our aim was to produce a final map that depicted a set of areas interacting in a homogeneous way with the urban atmosphere. These were named homogeneous climate-response units (HCR Units).

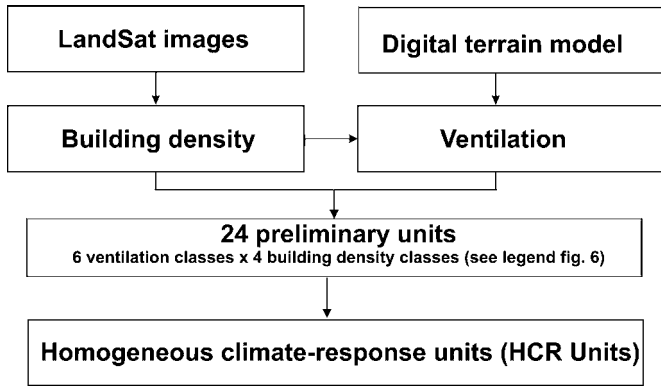


Fig. 3. Procedure followed in preparing the homogeneous climate-response units map.

This is a concept similar to the “climatopes”, defined by Scherer et al. (1999, p. 4187) as “areas of characteristic combination of climatic factors and of similar relative significance for their surroundings, operating on a spatial scale of several tenths to hundreds of meters”.

The HCR units climatic significance is potential, that is they are defined and delimited according to “climatic factors” (i.e. features that influence climate, such as altitude or urban geometry) and not according to the spatial variation of “climate elements”, such as temperature or humidity.

This map was an indispensable tool in defining the limits of the different areas for which climatic guidelines were to be put forth

(Fig. 7). The procedure that was followed in pursuing this aim is represented in Fig. 3. The built density and the ventilation maps (Figs. 4 and 5) were produced as an aid to draw the limits of the HCR Units. The methodology to define these units is mainly objective, but there were several final subjective adjustments, such as roughness length (z_0) thresholds, altitudinal limit for the low lying areas, etc. (see below).

2.2.1. Built-density map

The first step involved the classification of land cover, having as main criteria the urban physical characteristics, particularly built density. Several kinds of automatic classifications were carried out (minimum distance, maximum likelihood and the parallelepiped classifiers). The classification algorithms were applied to three Landsat images (from February 1992, August 1994 and July 1997) and one SPOT image from July 1991. Training sites were obtained from each roughness length class areas (see Section 2.2.2). The errors associated to each classification algorithms were calculated in order to choose the most accurate one: maximum likelihood classification of the Landsat image of February 1992 was selected. The resulting map was subsequently updated with information provided by the city authorities (mainly referring to green areas) and simplified according to the planners’ needs. The following four main groups were obtained (Fig. 4): (a) High density urban areas (where buildings occupy circa 50% of the total floor area). In the central part of the city, in between the downtown area (1, Fig. 1) and the Avenidas Novas (2, Fig. 1), high density urban areas prevail and green spaces are conspicuously absent; (b) Medium density urban areas (where buildings cover between 15% and 30% of the total

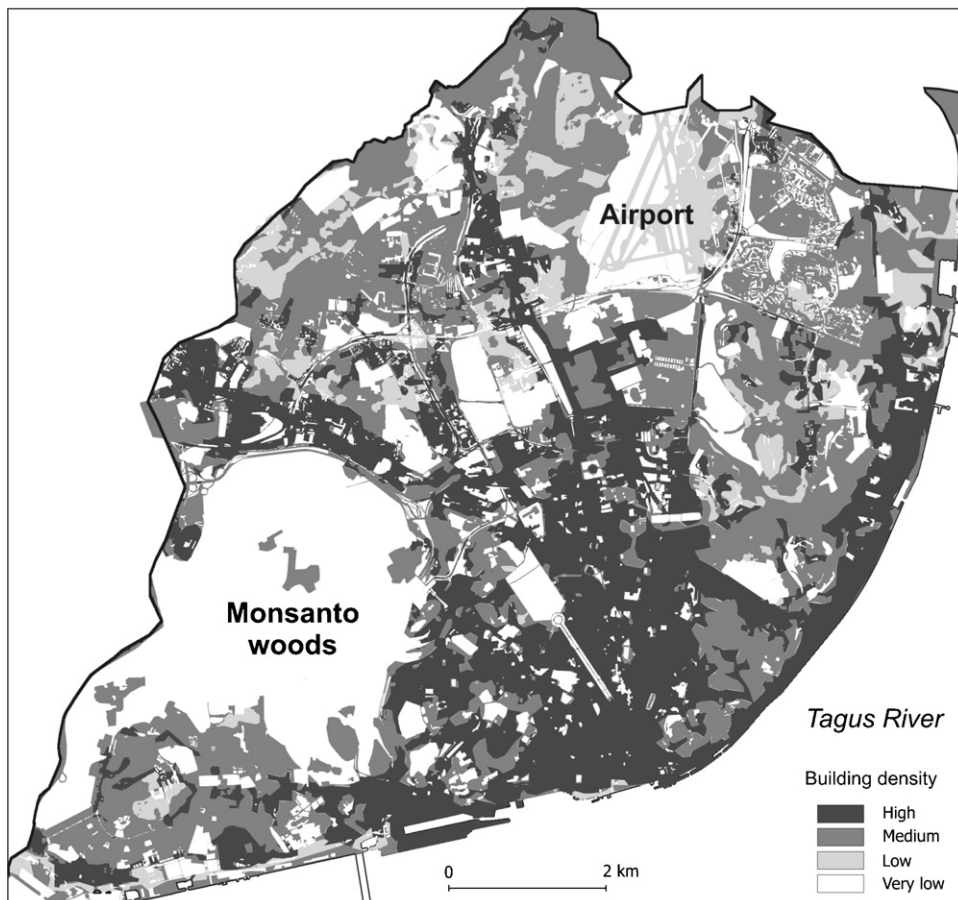


Fig. 4. Built density map.

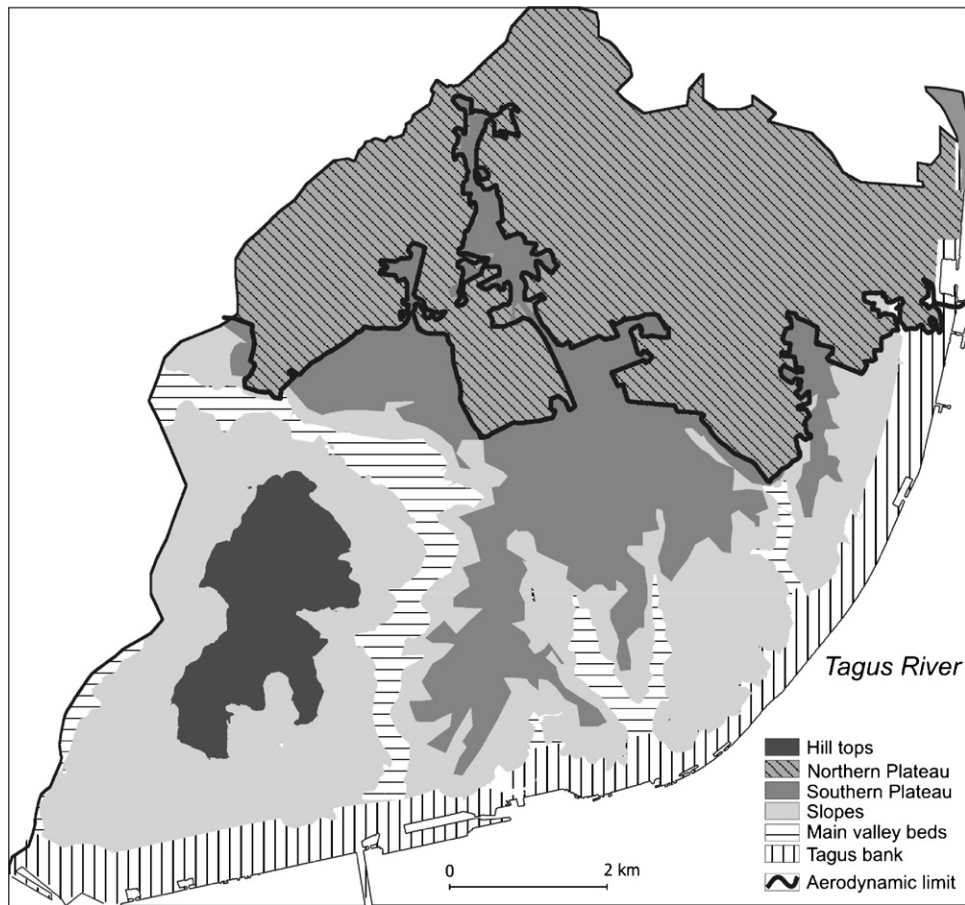


Fig. 5. Ventilation map, based on topography and aerodynamic limit (see text for explanation).

area); (c) Low density urban areas (where buildings cover less than 10% of the total area). The northern periphery of the city is characterised by relatively low urban density, particularly around the Airport area (5, Fig. 1), where the green spaces essentially consist of grasslands; (d) Very low density urban areas (where green spaces prevail). The largest (mainly forested) green area corresponds to the Monsanto hill, in the SW of the city.

2.2.2. Ventilation map

It is clear that in order to improve the air quality and to avoid thermal stress, the wind circulation should not be hampered. The main factors modifying wind circulation (topography and built density) are synthesised in the ventilation map (Fig. 5). Ventilation classes can be defined as areas with “characteristic combinations of climatic factors controlling local and regional wind fields and vertical air mass exchange processes, resulting in typical and distinctive ventilation conditions” (Scherer et al., 1999).

As the scale of analysis is mesoclimatic, the topography was the main determinant factor in the elaboration of this map (Figs. 3 and 5). A Digital Terrain Model (DTM) was used, allowing for the identification of the large morphologic units: the valley beds and the tops were limited by subtracting the values of the absolute altitudes from the statistical trend of the relief. The negative values indicate the areas at low levels, whereas the positive ones correspond to tops. Slopes with inclinations greater than 4° were identified automatically using GIS techniques. The tops are nearly always well ventilated areas. The flat areas, in which the slope is lower than 4° , constitute the Plateau. Monsanto is a 200 m hill, located to the west of the city’s main districts.

The low-lying areas are prone to be sheltered; however, when the frequent N winds are blowing these areas correspond to paths along which the winds are channelled. The ventilation along the valley beds must absolutely not be hindered for air quality and thermal comfort sake. The low-lying areas near the Tagus, particularly affected by river and ocean breezes, were included in a separate class (Tagus bank), limited by the 20 m contour line. This threshold was chosen based on the fact that the estuarine breeze progression to the interior is limited by a topographic “step”, upwards from circa 20 m altitude. As referred above, the prevailing N and NW wind circulation is influenced by the topography, but the winds are becoming increasingly hindered by the densely built-up neighbourhoods. Using a numerical model (WASP, Mortensen et al., 1993), the reduction in the summer wind speed due to surface roughness was simulated by Lopes (2002, 2003). It was found that the decrease in the wind speed is particularly important in the densely built-up southern city districts. The significant differences between built density and building height in Northern and Southern Lisbon have clear consequences on surface roughness. To quantify this parameter, z_0 values were assigned to the different city districts, according to the Davenport-Wieringa roughness length classification (Stull, 2000), that was also used for the European Wind Atlas and by the Danish Wind Industry Association. According to this criteria, the city centre and the new centrality area (1, 2, Fig. 1), were assigned a z_0 value of 1 m, and Monsanto hill of 0.7 m. In the northern part of the city, open spaces with some houses and green areas were assigned a z_0 value of 0.03 m, ancient residual farmland and vacant spaces, 0.02 m, and the airport runways (5 in Fig. 1) 0.01 m.

In order to include this information, a line representing the aerodynamic limit (Fig. 5) has been drawn: it separates the areas where a significant reduction of wind speed occurs, with z_0 between 0.7 m and 1.0 m (mainly in southern Lisbon) from the area with z_0 values between 0.01 m and 0.05 m in northern Lisbon, where wind speed is hardly affected, since the topography is rather flat and the urban density not yet very high.

2.2.3. Homogeneous climate-response units of the city of Lisbon (HCR Units)

The following step consisted in the creation of a co-occurrence matrix of the land cover/urban density and ventilation classes (Fig. 3 and legend of Fig. 6). The total number of resulting classes (24) was too high for planning purposes and, moreover, not all the possible classes actually occurred or occurred with little significant extension. For these reasons, a decision was made to aggregate some of the classes, taking into account the areas for

which the guidelines would most likely be similar. Previous knowledge of Lisbon's urban climate showed that this semi-quantitative methodology generated better results than a merely quantitative classification. The classes thus obtained were named homogeneous climate-response units (HCR Units), are presented in Fig. 6 and will be briefly described. For the ventilation units (*tops, Plateau and slopes*) the limits of the HCR units and, consequently, the guidelines for planning were a function of the built density (Fig. 6). The other two ventilation units (*Tagus bank and Valley beds*) were considered independently of the built density.

Class 1 refers to areas of very high built density, on hill tops, slopes or the southern Plateau.

Class 2 aggregates areas of medium and low built density in southern Lisbon. This aggregation was carried out because, on the one hand, the initial eight classes from the matrix (Fig. 6) were not continuous in space and, on the other hand, the guidelines to be applied were the same.

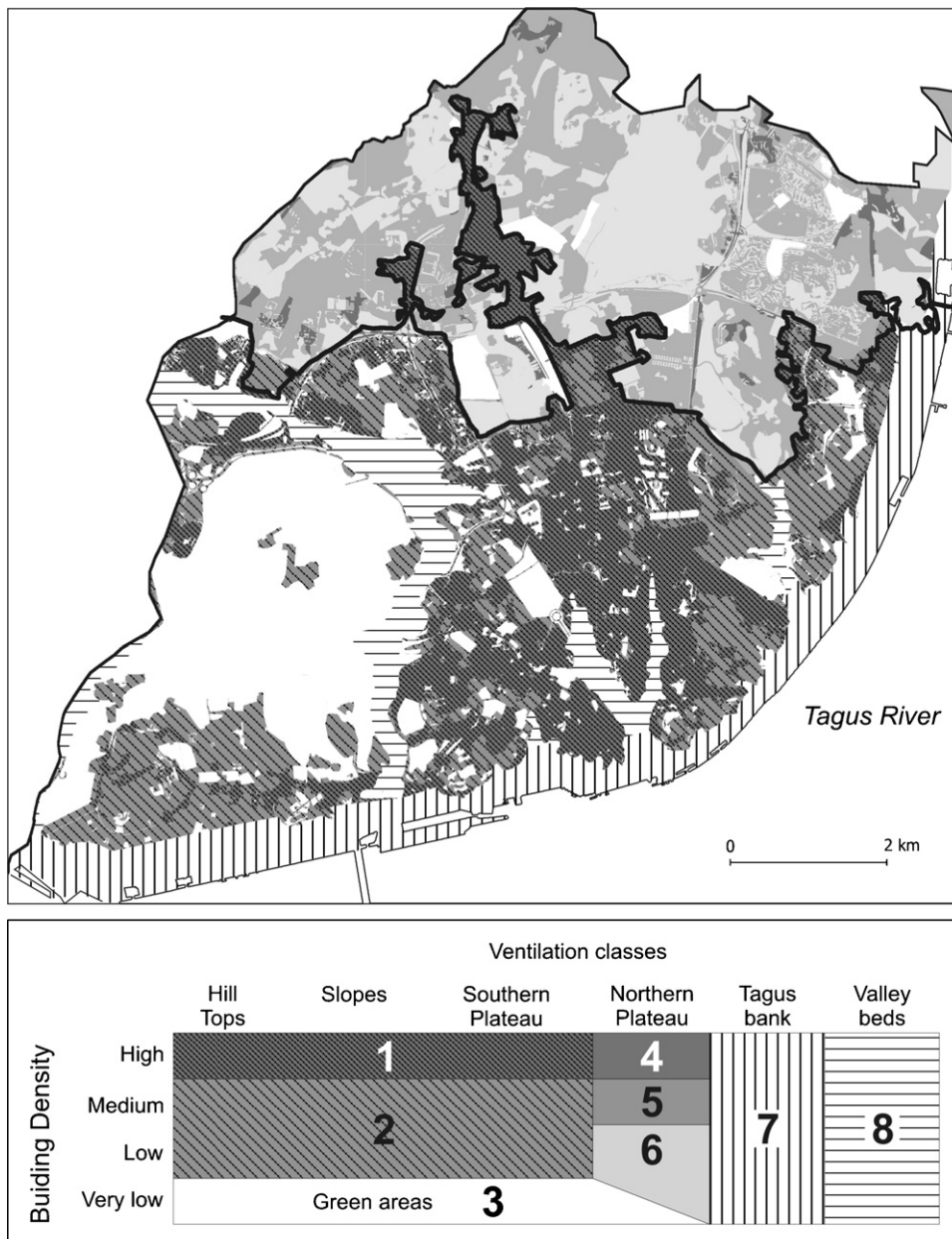


Fig. 6. Homogeneous climate-response units (HCR Units).

The green areas (3, Fig. 6) were delimited based solely on their land cover characteristics, i.e. regardless of their topographical position. In the northern Plateau the “green areas” include only arboreal vegetation. Low lying vegetation was excluded from class 3, because it does not hinder wind circulation and was therefore included in class 6.

In the case of the Plateau areas to the north of the aerodynamic limit, a decision was made to introduce a further and more detailed subdivision (numbers 4–6). This decision was based on the fact that the future densification of this area will influence not only the microclimates of the newly created districts, but also the climate of the entire city (for example, if the density of the built-up areas in this part of the city was to increase in such a way that the roughness length increased well beyond its current levels, the prevailing northerly wind would be much less effective in removing pollutants in the southern districts). Classes 4 and 5 include high and medium built density areas, while in class 6, low built density areas and areas of low lying vegetation have been considered. As stated above, two low-lying areas were delimited without regard for their land cover characteristics. These are the Tagus bank (7, Fig. 6), an HCR unit that comprises those areas in which the breezes are an important climate resource that must be preserved, and the valley beds (8, Fig. 6), where wind channelling and the cool air drainage are significant factors (most of the valley beds have a North-South orientation, which is also the prevailing wind direction).

It was now possible to put forth recommendations of land use transformations aimed at using the delimited areas in more appropriate or efficient ways or at addressing the problems inherent to their current usage (Scherer et al., 1999).

3. Results: climatic guidelines for planning

The aim of our research was to put forth a series of measures aimed at minimising the two sets of climatic problems that were identified: the UHI (that should be considered as a thermophysiological factor and not simply as a feature of the air temperature field) and poor ventilation. In areas with hot summers, UHI has a very negative effect, by increasing the level of discomfort and creating health problems for the city dwellers; furthermore, it raises the level of oxidant pollution and increases the energy and water consumption. In global warming scenarios, the UHI will increasingly become a major consideration. In this context, it was decided that the mitigation of the UHI should be a priority. Moreover, new urban developments should not hinder ventilation to an even greater extent, because the poor air circulation contributes toward increasing the UHI and decreasing the air quality. The aim of the suggested guidelines is that they are applicable at city scale and clear enough to be read by non-specialists; therefore, they must be simple and somewhat general in content; with more details supplied at a later date (within the frame of urbanization plans). As guidelines vary with location within the city, urban density and roughness, as well as with topography, they will be described separately for each HCR Unit.

- Areas of high urban density in the Southern Plateau (1, Figs. 6 and 7) – They include the old city centre and most of the city that was built before the 1950s. There are hardly any open spaces. The main guidelines are: (i) to avoid increasing built density in valley beds, without a detailed study of the consequences on the ventilation in the valley; (ii) to make sure that the H/W ratio (i.e. the ratio between the height (H) of the buildings and the width (W) of the streets) is kept under 1, in those cases where urban development is currently under way; (iii) to maximize the vegetated surfaces, including roof gardens; (iv) when renovating

buildings, opt for light colours and materials with low thermal admittance (Oke et al., 1991; Doulos et al., 2004).

- Areas of low and medium urban density in the Southern Plateau (2, Figs. 6 and 7) – The main guidelines are: (i) to limit urban developments in valley beds (ii) to make sure that the H/W ratio is kept under 1; and (iii) to create medium-sized green areas.
- Areas of low and medium urban density in the Northern Plateau (5 and 6, Figs. 6 and 7) – The southern limit of this area corresponds to the aerodynamic limit, which means that the gradient wind remains relatively unobstructed by urbanization. If this situation remains unchanged, positive consequences are to be expected in terms of the prevention of overheating and of excessively high pollution levels not only for the northern city districts but also for central and southern Lisbon, in terms of the prevention of overheating and of excessively high pollution levels. As this is obviously an area subject to great pressure from urbanization, particularly in its NW sector, the guidelines are the following: (i) to avoid increasing the built density (H/W should be lower than 1); (ii) to promote ventilation paths alongside large freeways or in between the city districts; and (iii) to create large green areas next to each newly-built urbanised neighbourhood quarter. The areas of high density in the northern Plateau (4, Fig. 6) are very small and have not been considered at the mesoscale
- Tagus Bank (7, Figs. 6 and 7) – In the S and SW Tagus Banks, the built density is already relatively high, even though the height of the buildings is on average less than 15 m. However, new city districts have been created in eastern Lisbon over the last decade. As urban development proceeds, planners should be aware that buildings whose larger side runs parallel to the river bank prevent the inland penetration of cool air. Thus, the creation of wind corridors with low roughness levels is recommended, in order to allow for the circulation of the estuarine breezes (for example, by keeping z_0 under 0.5 m, so as to avoid reductions in the wind speed by more than 0.3 m/s).
- Ventilation paths (Fig. 7) – Besides the referred HCR Units, it was considered necessary to indicate paths that should be kept free for prevailing wind circulation towards the city core (ventilation paths, Fig. 7). The ventilation paths were delimited based on a combination of three main factors: topography (in southern Lisbon, it corresponds to the main *valley beds*, n.8 in Fig. 6), built density (low density axes in northern Lisbon, part of unit 6 in Fig. 6) and orientation (along a roughly N–S direction). In order to ensure adequate ventilation in these paths, (i) no urban developments (especially tall buildings with a E–W orientation) should be allowed without a detailed study of future consequences on ventilation leewards and (ii) the trees planted along these axes should not form dense windbreaks. Compliance with these guidelines will ensure that good ventilation leads to positive effects in terms of temperature and air quality.
- Green areas (3, Figs. 6 and 7) – The positive (biophysical, social, cultural, etc.) influence of urban green areas is well known. The diversification of the structure of the inner green areas (ponds, lawns, tall trees, shrubs) would give rise to several different types of microclimates, which in turn would favour different types of uses in different times of the year. Beside their influence within the green areas themselves, it is well known that medium and large-sized parks modify the atmospheric conditions in the surrounding neighbourhoods (Oke, 1989; Spronken-Smith and Oke, 1998; Eliasson and Upmanis, 2000; Andrade and Vieira, 2007) and filter some of the air pollutants (Kuttler and Strassburger, 1999; Upmanis et al., 2001). Therefore, it is advisable to (i) preserve the existing green areas (ii) create new ones wherever there is enough available space. Furthermore, (iii) the new green spaces should have a diversified inner structure and (iv) dense windbreaks should be created windward from their leisure areas.

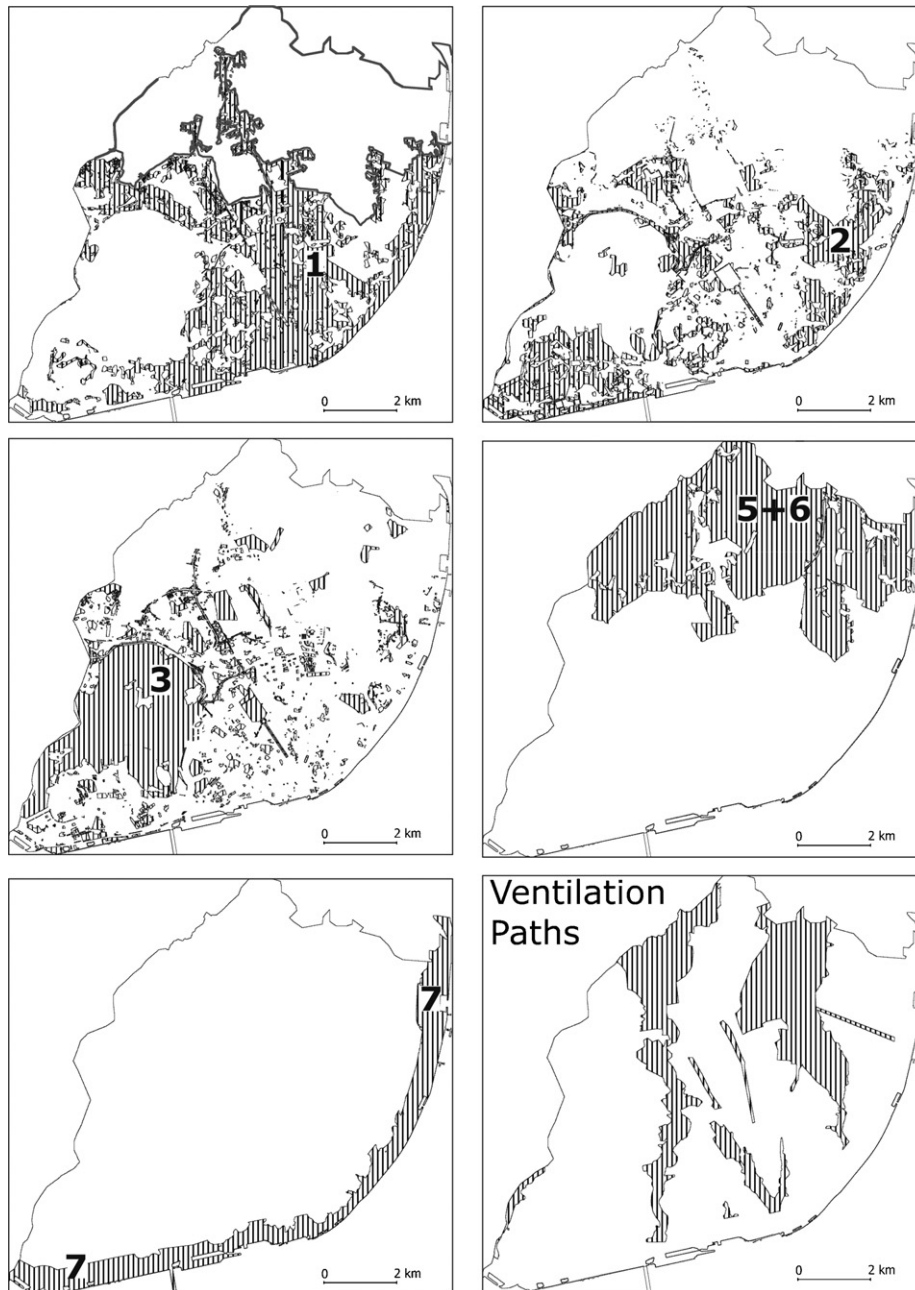


Fig. 7. Homogeneous climate response units for which climatic guidelines were put forth.

4. Discussion

In order to improve the quality of life of the city dwellers and to ensure urban sustainability, several measures have to be taken. The methodology that was used in order to translate the urban climate knowledge into information that is useful to planning was in this case applied to the city of Lisbon. It may be adapted so as to be used elsewhere in a systematic way, particularly in areas undergoing rapid urbanization.

This method has several advantages (i) it gives spatialized climatic guidelines for the entire city; (ii) it is sufficiently simple to be easily understood and implemented by non-climatologists; (iii) it provides a framework for the introduction of subsequent microclimatic guidelines; (iv) the “climatic guideline layer” can be superposed onto other layers in order to create different types of

maps. At this stage, there are mainly two limitations for the application of this methodology (i) it requires subjective assessments at the different stages; (ii) it is only adequate to be implemented at the city scale.

Upon finishing this study, it is important to systematize the main problems that arose during this research on applied urban climatology and thereby contribute to an enlarged discussion on this topic.

First of all, it is important that the researcher be aware of the different scales at which the work should be carried out, because it may be necessary to adopt different approaches. This paper is essentially based on the results of a city scale project, but it was followed by the microclimatic study of a specific neighbourhood. It is important to consider that conflicts can arise between the planning guidelines for the two different scales and

that have to be dealt with. For example, large ventilation paths were recommended at the settlement scale, whereas in certain Lisbon city districts, guidelines were put forth that included the provision of shelter in certain outdoor areas used for leisure activities.

Secondly, adequate climatic and geographical databases and appropriate cartographical tools are indispensable. Data from “classical” meteorological stations are not appropriate in the context of urban studies. Over the last few decades, there have been significant developments in the field of the measurement methodologies and data collection techniques used in urban areas (Oke, 2004; Grimmond, 2006). The advances in modelling and the improvement of the measurement devices have made it possible to carry out the present study. Obviously, it is also necessary to rely on up-to-date, detailed and accurate geographical data (including satellite images), as well as on the use of GIS.

Third, at the beginning of each study, it is crucial that the main planning needs be identified and highlighted, in order to make it possible to mitigate the negative impacts and maximize the positive features of the urban climate. In areas with contrasting thermal seasons, the UHI may be a positive feature in the winter, but negative in the summer. The energy saving that occurs in the winter in cities with a Mediterranean climate is less significant than the additional expenses incurred into in cooling the cities in the summer (Givoni, 1998; Hassid et al., 2000; Akbari et al., 2001; Santamouris et al., 2001). Moreover, higher temperatures have a number of other negative consequences, such as the increase in morbidity and mortality associated with heat waves (Kalkstein, 1997; Koppe et al., 2004), oxidant pollution, bacteria proliferation, among other things. All these problems of urban areas are aggravated in a context of global warming. This study adopts therefore the stand that UHI must be mitigated. However, a case-by-case assessment must be carried out and accordingly, the solutions must always be tailored to the specific circumstances of the areas under study. Similar decisions have to be made with regard to other climatic elements, such as radiation, wind, driving rain, snow, etc. The climatic guidelines that are put forth virtually always represent a compromise between the optimal measures to address each climatic aspect (Zrudlo, 1988).

Fourth, the interaction with the planners is obviously indispensable. The dialogue with Lisbon City planners grew easier as work progressed and parts of some maps were in fact jointly drawn. Furthermore, an effort is being made to disseminate the idea that climatic guidelines should be systematically included in planning urban municipalities.

5. Concluding remarks

The *metutopia*, referred to by Landsberg in 1973, obviously cannot be attained; however, it is possible to make headway towards the high climatic quality city, as defined by Bitan in 1992. It is well known that planning involves quite complex procedures, and that the climatic aspects are seldom considered as the most important ones, as other environmental and socio-economic features are usually afforded greater priority in the selection of planning measures. However, both planners and the public should bear in mind that taking the climate into account in the selection of the planning procedures may also have a number of economic and social consequences, namely with respect to energy consumption and the health of the urban dwellers; this pays testimony to the importance of applied climatic urban studies.

It was not until the late 20th century that joint research was carried out by a number of university departments (quoted above) alongside city authorities, aimed at incorporating climatic information in urban planning. In the Portuguese case, this research proved an excellent opportunity to move from theoretical consider-

ations to applied research. Examples of simple climatic guidelines for urban areas were provided because management plans usually only include general, and nearly always inadequate, considerations with respect to the climate. The authors have also sought to contribute to furthering the discussion with respect to the choice of the best methodology and to highlight the importance of systematically carrying out these types of studies within the scope of city and land use planning at a variety of scales.

Matzarakis (2005) states that “the impetus for the *Climate Booklet [for Urban Development (Baumüller, 2005)]* was an amendment to Germany’s existing Federal Building Law with its new requirements for consideration of climatic conditions in zoning and planning”. There is still no legislation on this topic in Portugal, but the fact that the present results are going to be published as a supplement to Lisbon’s Master Plan may contribute towards increasing public awareness of the importance of the introduction of climate guidelines in urban planning.

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