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## URBAN BIOCLIMATE AND COMFORT ASSESSMENT IN THE AFRICAN CITY OF PRAIA (CAPE VERDE)

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**Abstract** – The population of Praia (Ilha de Santiago/Cape Verde) has recently increased from 90,000 inhabitants in 2000 to 132,300 in 2012. Located in the southern part of the Santiago Island, the city has an average temperature of 22°C and high values of humidity. The hot and rainy season occurs between July and October. According to the Cape Verde “National Climate Change Adaptation” report, the temperatures increased about 1°C in the last 15 years and scenarios indicate an annual warming between 0.7°C and 2.5°C until 2060. This will lead to the deterioration of bioclimatic comfort conditions, especially in urban areas. The main goals of this research are: i) to make a first-hand assessment of bioclimatic conditions and human comfort in the city of Praia; ii) to evaluate the main microclimatic and urban factors that increase thermal stress in a “planned” neighbourhood (Palmarejo). It was shown that “moderate and strong heat stress” (PET>29°C) occurs between August and October. The rest of the year hardly any heat stress occurs (18°C<PET<29°C). In the Palmarejo neighbourhood, heat stress in hot days (PET>40°C) happens especially in poorly ventilated streets, well exposed to the sun.

**Keywords:** Urban bioclimatology, thermal patterns, heat stress, PET, Praia, Cape Verde.

**Resumo** – AVALIAÇÃO DO BIOCLIMA URBANO E DO CONFORTO TÉRMICO DA PRAIA (CABO VERDE). A população da cidade da Praia aumentou de 90 000 habitantes, em 2000, para 132 300 em 2012. Localizada no litoral meridional da ilha de Santiago, Praia regista

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todo o ano valores elevados de humidade, e temperatura média superior a 22°C. O período mais quente do ano, entre Julho e Outubro, coincide com a estação das chuvas. De acordo com o “Plano Nacional de Adaptação às Mudanças Climáticas de Cabo Verde”, a temperatura do ar aumentou cerca de 1°C na região, nos últimos 15 anos admitindo-se uma subida da temperatura média anual entre 0,7°C e 2,5°C até 2060. Prevê-se, assim, que ao longo deste século se degradem as condições de conforto bioclimático, particularmente nas áreas urbanas. Os principais objectivos deste estudo são: i) fazer uma primeira avaliação das condições bioclimáticas e do conforto humano na cidade da Praia; ii) determinar os principais factores microclimáticos e de morfologia urbana, que incrementam as situações de *stress* térmico no bairro do Palmarejo, na parte ocidental da cidade, escolhido para este estudo microclimático. No período mais quente e húmido do ano ocorrem predominantemente as situações de *stress* térmico “quente e muito quente” (PET > 29°C), ao passo que o resto do ano é considerado “confortável” ou “ligeiramente quente” (18°C < PET < 29°C). No interior do bairro do Palmarejo, o *stress* térmico em dias quentes pode ser mais acentuado nas ruas bem expostas à radiação solar directa e naquelas onde a ventilação é fraca, normalmente perpendiculares ao vento dominante de nordeste-aliseo (PET > 40°C).

**Palavras-chave:** Bioclimatologia urbana, padrões térmicos, *stress* térmico, PET, Praia, Cabo Verde.

**Résumé** – EVALUATION DU BIOCLIMAT URBAIN ET DU CONFORT THERMIQUE À PRAIA (RÉPUBLIQUE DU CAP VERT). De 2000 à 2012, la population de la ville de Praia, dans l’île de Santiago, est passée de 90 000 à 132 300 habitants. Située sur le littoral sud, la ville enregistre des valeurs élevées d’humidité et une température moyenne mensuelle toujours supérieure à 22°C. La période la plus chaude coïncide avec la saison des pluies, de juillet à octobre. Selon le « Plan National d’Adaptation aux Changements Climatiques », la température moyenne de l’air a augmenté de près de 1°C en 15 ans et un accroissement moyen annuel de 0,7 à 2,5°C est prévu jusqu’en 2060. On pense donc que les conditions bioclimatiques vont se dégrader au cours du prochain siècle et surtout dans les aires urbaines. Objectifs principaux de la présente étude : i) Réaliser une évaluation provisoire des conditions bioclimatiques et du confort humain à Praia et ii) Déterminer les principaux facteurs microclimatiques et de morphologie urbaine qui accentuent les situations de *stress* thermique dans le quartier de Palmarejo, à l’ouest de la ville. Les situations de *stress* s’y produisent surtout pendant la saison la plus chaude et la plus humide (PET > 29°C). Le reste de l’année, le temps est «confortable» ou «assez chaud» (18 < PET < 29°C). Dans ce quartier, le *stress* thermique de saison chaude est plus fort dans les rues mal ventilées, perpendiculaires au vent dominant de NE, l’alizé, et dans celles qui sont le plus exposées à la radiation solaire directe (PET > 40°C).

**Mots-clés:** Bioclimatologie urbaine, champs thermiques, *stress* thermique, PET, Praia, République du Cap Vert.

ملخص - تقييم المناخ الحيوي والراحة الحرارية في برايا (جمهورية الرأس الأخضر). ارتفع عدد سكان مدينة برايا، في جزيرة سانتياغو، بين سنة 2000 و2012، من 90 000 إلى 132300 نسمة. وتقع مدينة برايا على الساحل الجنوبي، وتسجل قيما عالية للرطوبة ودرجة حرارة متوسطة شهرية تفوق 22 درجة. وتزامن الفترة الأكثر حرارة مع موسم الأمطار، من يوليو إلى أكتوبر. وحسب "الخطة الوطنية للتكيف مع التغيرات المناخية"، ارتفعت درجة حرارة الهواء المتوسطة ما يقرب درجة مئوية واحدة في 15 سنة و يتوقع أن تسجل زيادة سنوية متوسطة تتراوح ما بين 0,7 و2,5 درجة مئوية إلى غاية 2060. لذلك يعتقد أن الظروف المناخية الحيوية ستتدهور خلال القرن المقبل، وخاصة في المناطق الحضرية. الأهداف الرئيسية لهذه الدراسة: أولاً: إجراء تقييم مؤقت للظروف المناخية وراحة الإنسان في برايا. ثانياً: تحديد العوامل المناخية المحلية والبنوية الحضرية التي تزيد من حالات الإجهاد الحراري في حي بالمريجو، غرب المدينة. وتحدث حالات الإجهاد هناك خصوصاً خلال الموسم الأكثر حرارة و رطوبة (حيث يكون مؤشر الدرجة المكافئة الفسيولوجية الحرارية أعلى من 29 درجة مئوية). أما بقية العام، فيكون الطقس "مريحاً" أو "ساخناً بما فيه الكفاية" (حيث ينحصر مؤشر الدرجة المكافئة

الفسيوولوجية الحرارية ما بين 18 و 29 درجة مئوية). وفي ذلك الحي، يكون الإجهاد الحراري في الموسم الحار أقوى في الشوارع سيئة التهوية، العمودية بالنسبة للرياح السائدة الشمالية الشرقية، الرياح التجارية، وأيضا في الشوارع الأكثر تعرضا للإشعاع الشمسي المباشر (حيث يكون مؤشر الدرجة المكافئة الفسيولوجية الحرارية أعلى من 40 درجة مئوية).

كلمات البحث: علم المناخيات الأحيائية الحضرية، الحقول الحرارية، الإجهاد الحراري، الدرجة المكافئة الفسيولوجية الحرارية الحار، الدرجة المكافئة الفسيولوجية الحرارية، برايا، جمهورية الرأس الأخضر

## I. INTRODUCTION

The city of Praia (Santiago Island) is the capital of Cape Verde Republic, an insular country with 10 main islands located 500 km off the Senegalese western coast of Africa. According to the Census of 2010 (INE-CV, 2010), 491,683 people inhabit nine islands (S. Luzia is uninhabited). Out of the total population 303,673 people (61.8%) live in urban areas. As in other developing countries in Africa, severe droughts, soil and coastal erosion and flash floods are some of the environmental hazards that threaten its populations. Another natural hazard, such as dust storms, known locally as *Bruma Seca* or *Lestada* (i.e. the Harmatan, a Sahara flux from the African continent towards the islands occurring from December to March) frequently have severe impacts at social (health problems and loss of life) and economic levels, mainly due to transport (land, air and sea) shutdown. The occurrence of these episodes makes Cape Verde society very dependent on the duration and intensity of natural hazards.

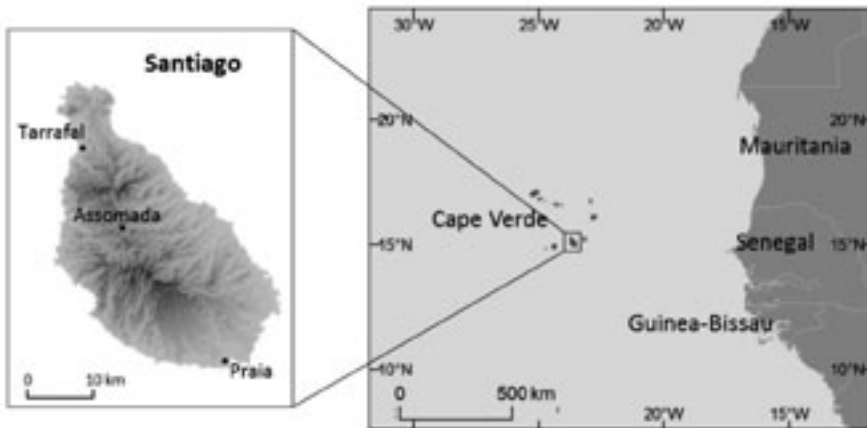


Fig. 1 – Location maps of Cape Verde (right) and Praia in the Santiago Island (left).

Fig. 1 – Arquipélago de Cabo Verde (à direita) e a cidade da Praia na Ilha de Santiago (à esquerda).

Source: SRTM Data

Recently, new concerns related to thermal comfort and air pollution, have arisen due to the fast urban growth in several African cities (Lioussé *et al.*, 2014). However, only a few studies have been conducted in Africa, namely in South-Africa (Becker, 2000), Algeria (Ali-Toudert *et al.*, 2005), Angola (Ferreira-Baptista and De Miguel, 2005), Morocco (Johansson, 2006), Tanzania (Ndetto and Matzarakis, 2013a; Ndetto and Matzarakis, 2013b), and Nigeria (Eludoyin *et al.*, 2014; Balogun and Balogun, 2014). Unfortunately some urban environmental hazards (especially human thermal discomfort) have not received much attention from national and international agencies. Until now it is obvious that the major concerns for the “underdeveloped” economies are related with primary assistance (food, health and fresh water supply) rather than with heat stress mitigation. Nevertheless, part of African population currently have access to consumption goods with strong energy impact, such as individual transportation, massive use of air conditioning, etc. Furthermore, Africa will have more urban dwellers and one of the largest population growth until 2050, with an expected 1,300 million increase (total of 2,431 million in 2050), exceeding the population-giant Asia rate (from 4,302 million in 2013 to 5,284 million in 2050, Haub and Kaneda, 2013). According to the same source of information, Cape Verde will have a rate of natural increase of 1.5%, reaching about 700,000 inhabitants in the middle of the century (the 2010 Cape Verdean census registered 491,683 inhabitants).

Along with the demographic explosion, the emissions of gases and particulate matter from fossil fuels combustion will impoverish the air quality in the near future in many African cities (Lioussé *et al.*, 2014). This will significantly modify the chemical composition of the urban boundary layer with consequences in the thermal patterns of the cities. We should note that the use of coal for home cooking in Cape Verde is a generalized practice nowadays; in fact, coal and wood are used by 32.1% of the dwellers in the archipelago (9.7% in urban areas - INE-CV, 2010).

Biometeorological and urban climate is a rapid expanding field (Gosling *et al.*, 2014). In Africa, climate studies are more focused on the impacts of heat stress on human health and livestock than on human thermal comfort in outdoor conditions, as it was shown recently by Eludoyin *et al.* (2014). The causes are related with shortage of meteorological data in African cities and other priority needs related with immediate daily survival (Roth, 2007).

The Physiological Equivalent Temperature (PET) is a thermal index derived from the human energy balance (Matzarakis *et al.*, 1999). PET corresponds to air temperature at a typical indoor setting in which an individual with normalized characteristics (sex, age, height, clothing, etc.) has the same physiological responses (skin temperature, core body temperature and sweating) as in a given real environment (Höppe, 1993 and 1999). PET is used to characterize the thermal bioclimate and is also suitable to urban and regional planning, whenever a thermal assessment is required (Matzarakis *et al.*, 1999). Compared to other thermal indices PET has the additional advantage of using the widely known Celsius scale (°C) that is easily understood by urban planners and decision makers. PET can be used in all

year round studies in different climates (Lin and Matzarakis, 2008; Zaninović and Matzarakis 2009; Lopes *et al.*, 2011) and it has been used in several regions with hot-humid climate in Southeast Asia (Lin and Matzarakis 2008; Nasir *et al.*, 2012) and Africa (Johansson, 2006; Ndetto and Matzarakis 2013a and 2013b; Omonijo *et al.*, 2013). The current study will show that this index is suitable to be applied in Cape Verde, although some adjustments to adapt physiological stress thresholds should be made in the future. The use of PET allows to build ranges of thermal perception and grades of physiological stress on humans for different regions and climates enabling the comparison between different regions (Lin and Matzarakis 2008; Omonijo and 2013; Tzu-Pin *et al.*, this issue).

The main objectives of this study are: i) to make a first-hand assessment of biothermal conditions and human comfort in the city of Praia (Cape Verde) and ii) to determine the microclimatic features that act as urban climate constraints in a sprawling neighbourhood in the western part of the city. To address the first objective, meteorological data from the Praia/Airport station was used. This allowed us to show the frequency of thermal sensation classes and stress conditions in the main Atlantic tropical seasons (rain and dry season). To achieve the second objective, a microclimatological model (*Envimet*) was used to simulate wind speed and direction, mean radiative and air temperature and PET on a hot day. This allowed us to understand the importance of the wind, shade and vegetation in the streets as key factors to reduce outdoor thermal stress. The geographical characteristics of the study area are described in the next section. Details about the data and methodology used, such as the micrometeorological modelling, are presented in section III. Section IV includes the results and discussion and the conclusion is presented in section V.

## II. STUDY AREA

### 1. The city of Praia: population and growing patterns

Over 25% of the total population of the Cape Verde archipelago lives in the city of Praia. Its current population of 132,317 inhabitants has increased by 32% since 1990, and the current growth is about 3% per year. Until the 1930's, the city of Praia was confined to the *Plateau* (Medina do Nascimento, 2009). In the middle of the XX century, the surrounding hilltops were gradually occupied (fig. 2) and during the 1970's the vacant spaces were filled with new neighbourhoods, as a result of a spontaneous and unplanned manner, typical of many African urban sprawl processes (Medina do Nascimento, 2010). According to this author, more than 70% of the residential districts were built without proper planning or municipal licenses: 19 of the 31 residential neighbourhoods are predominantly unlicensed and many of the considered "formal" (planned) city-districts have illegal housing patches.

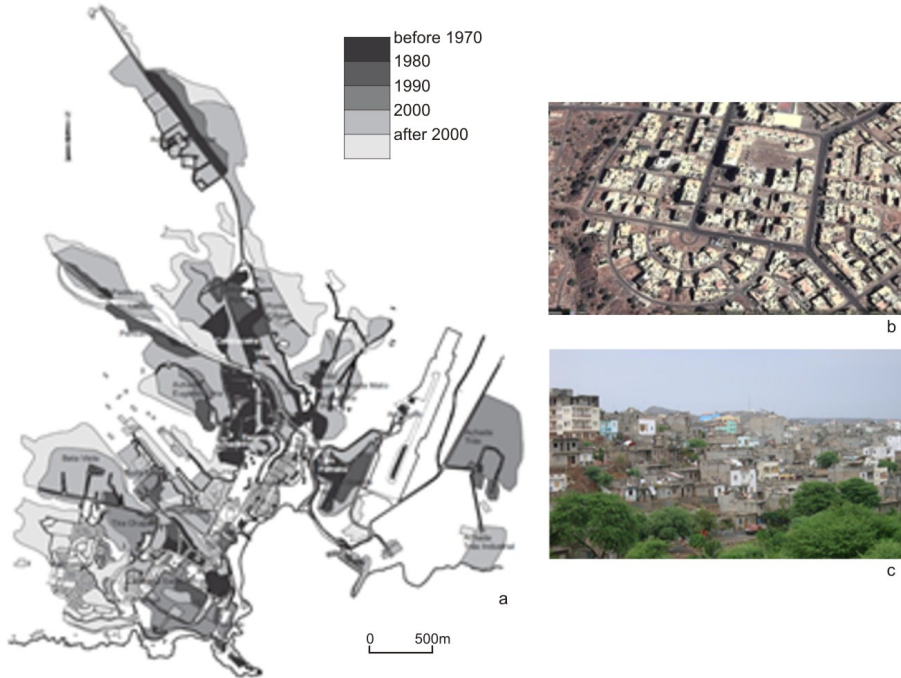


Fig. 2 – a) Growing patterns of Praia in the last century: b) “planned” city; c) “spontaneous” city.

Fig. 2 – a) Padrão de crescimento da cidade de Praia no último século:

b) cidade “planificada”; c) cidade “espontânea”.

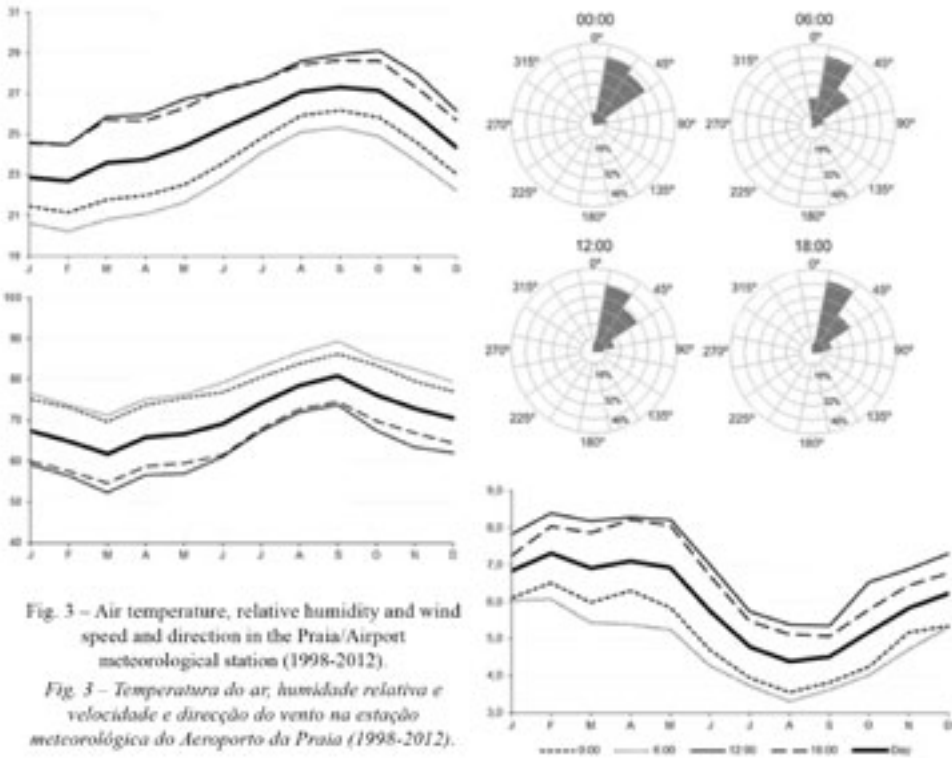
Source: Medina do Nascimento, 2010

The traditional rectangular grid of the Plateau (introduced during the Portuguese administration) was not applied in many other areas. The new sprawling areas have an irregular shape (with very heterogeneous urban occupation, street orientation and width), determined by the space available between the buildings. Another urban characteristic is the scarcity of green spaces. Obviously, the natural ventilation in those areas is affected, with the impoverishment of the air quality and thermal conditions in indoor and outdoor spaces.

## 2. Temperature and wind regime at the Praia/Airport meteorological station

According to the updated Köppen-Geiger climate classification (Peel *et al.*, 2007), the climate of Praia is hot and dry (*trockenes Passatklima*, BWh - Köppen, 1936), with a wet irregular season from July to October. The minimum air temperatures during the dry season (December to June) range from 21°C to 23°C and the maximum from 25°C to 27°C. During the dry and cooler period, the lower relative humidity occurs in March with values around 50% during the day and 70% during the night. In the wet and hot season the humidity is very high especially during the night (80 to 90%) and about 70% around noon and late afternoon (fig. 3a). It is also the hottest period of the year, with very hot nights, e.g.

from August to October the daily mean temperature remains above 25°C. The trade winds blow very regularly from NE all year round with high wind speeds in the dry season, especially during the day (8 to 9 m/s - fig. 3b). During the rainy season the wind speed drops to roughly 3 m/s during the night and 5 m/s during the day. The wet period from July to October, characterized by high temperature and humidity and low wind speed values, is locally known as “Azágua” and probably the most uncomfortable period of the year. The seasonality is, therefore, the main climate characteristic of Praia region, not only because of the rainfall occurrence but also due to other main climatic elements regime.



According to the latest report, published by the National Adaptation Programme on Climate Change (INMG, 2010), in the last 15 years the mean annual temperature in Cape Verde increased by approximately 1°C. Projected scenarios show an increase of 0.7 to 2.5°C by 2060 and of 1.2 and 3.7°C by the end of the century (McSweeney *et al.*, 2010). Furthermore, until 2060, an increase of 16 to 32% in the frequency of hot days (with temperatures exceeding the current 90<sup>th</sup> percentile) and 23 to 49% of hot nights is expected. According to the same authors, these figures become even more severe from August to October, the warmest period of the year. An impoverishment of the bioclimatic comfort conditions in the archipelago is expected, particularly in the urban areas that have grown significantly during this century.



### III. METHODS AND DATA

The regional thermal comfort assessment was made using PET (Physiological Equivalent Temperature). The calculations were performed using the RayMan software (Matzarakis *et al.*, 1999 and 2007), which is a simple model that uses meteorological data as input. Data registered at the meteorological station of Nelson Mandela Airport of Praia (about 3 km northeast of the city centre,  $\phi$ -latitude 14.9 N /  $\lambda$ -longitude, 23.5 W), during the periods of 1998-2006 and 2008-2012 was obtained from the National Climatic Data Centre (NCDC) (<http://gis.ncdc.noaa.gov/>, last accessed in January 2014). Hourly data of air temperature, wind speed, relative humidity and cloud cover (used to estimate radiative fluxes indirectly) at 0:00h, 06:00h, 12:00h and 18:00h UTC, were used to compute PET. The software calculates the Mean Radiant Temperature (MRT), the main radiation influence on the human body that, along with the other meteorological parameters, assesses the thermal comfort. This evaluation was accomplished by analysing the frequency of occurrence of thermal stress (PET) classes, shown in the next section (IV. 1).

The micrometeorological study of the Palmarejo area, a neighbourhood in the western part of Praia (fig. 4), was made using the *Envimet* software (Bruse and Fleer, 1998). This tool uses prognostic, non-hydrostatic, 3D micro-scale meteorological models with a horizontal resolution of 2 to 10 m and a vertical resolution from the surface to a few meters above the buildings. The model covers an area of about 18.3 ha. The simulations were performed during a clear sky “warm” thermal sensation day (maximum temperature > 30°C and PET=34°C), with a north-easterly wind with a speed of 4.6 m/s. These conditions were observed in the meteorological station of Praia Airport, on the 15<sup>th</sup> August 2012 during the afternoon (12:00h, local time) (table I). The upper-air sounding at 12:00h (launched in the Sal Island and published by the University of Wyoming <http://weather.uwyo.edu/upperair/sounding.html>, last accessed in January 2014) was used for the initial boundary conditions at 2,500m which is the vertical limit of the model. The vegetation in Palmarejo is predominantly made up of dry grass (with few small trees in the western part) and buildings with typically 3 to 7 stories (fig. 4).

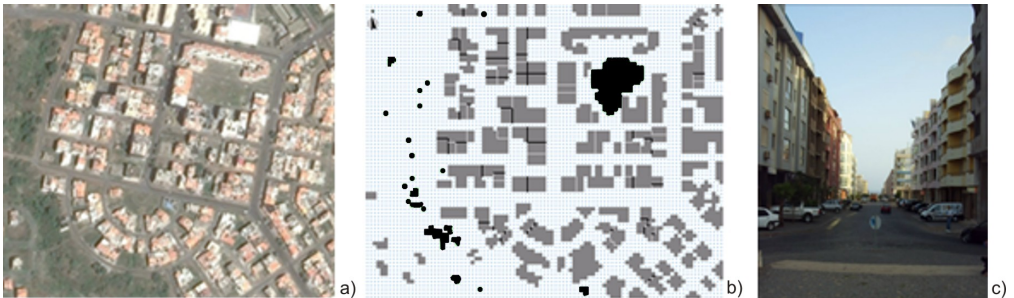


Fig. 4 – Palmarejo neighbourhood in Praia. a) Aerial View (Google maps);  
b) building/vegetation - Envimet model; c) north-south oriented street.

Fig. 4 – Bairro do Palmarejo na Praia. a) Vista aérea (Google maps);  
b) modelo Envimet do edificado/vegetação; c) rua com orientação Norte-Sul.

Table I – Metadata and initialisation parameters of the micrometeorological simulation with *Envimet* for the Palmarejo neighbourhood (Praia, Cape Verde), during a warm day (15th August 2012).  
*Quadro I – Metadados e parâmetros de iniciação de modelação micrometeorológica com o Envimet, no bairro do Palmarejo (Praia, Cabo Verde), num dia quente (15 de Agosto de 2012).*

Location ( $\phi$ , $\lambda$ , alt)	14.9 N, 23.5 W, 39m
Köppen Class	BWh
Horizontal area	$\approx$ 18.3 ha
Date; time shown	15th August 2012; 12:00h
Wind speed (m/s) & direction ( $^\circ$ ) (10m) (type)	4.6 ; 70 (trade winds)
Boundary conditions:	
Initial potential atmosphere temperature (2500 m)	$\theta = 310.4$ K
Specific Humidity (2500 m)	$q = 8.5$ g water/kg air
Relative Humidity (2m)	62 %
Grid size	95x77x40
dx, dy, dz (m)	5; 5; 2
Roughness length ( $z_0$ ) at Praia Airport (m)	0.03
Model rotation	11.5 $^\circ$

The software simulation yielded several layers of microclimatic data (programmed for every 3 hours, starting at 03:00 am to 21:00 pm during the 15<sup>th</sup> August 2012), from which we analysed the potential temperature ( $\theta^\circ\text{C}$ ), the Mean Radiant Temperature, the wind speed and direction and PET (the latter was calculated using the specific module - CalcPET). The results for noon (12:00h – solar time) are presented in the next section (IV. 2).

## IV. RESULTS AND DISCUSSION

### 1. Thermal comfort and heat stress in the Praia region

The regional thermal comfort in the Praia region is quite contrasted and can be divided into two annual and two daily categories (fig. 5): i) daytime (12:00h and 18:00h) of the dry season (from November to June) is dominated by “comfortable and slightly warm” thermal perception, although January and February have a fair frequency (40/50%) of “slight cold stress” in the beginning of the evening (18:00h); ii) during night time, a “moderate” to “slight cold stress” dominates the bioclimatic comfort; iii) the nights during the rainy season are, in general, comfortable; iv) however, during the day “moderate” to “strong heat stress” (PET between 29 $^\circ\text{C}$  and 40 $^\circ\text{C}$ ) is the most common grade of physical stress perceived, with more than 90% of the occurrences from August to October; at sunset the environment becomes much more pleasant. It should be pointed out that these conditions are based on observations at the airport, out of town, without the effect of the city on air temperature and ventilation conditions.

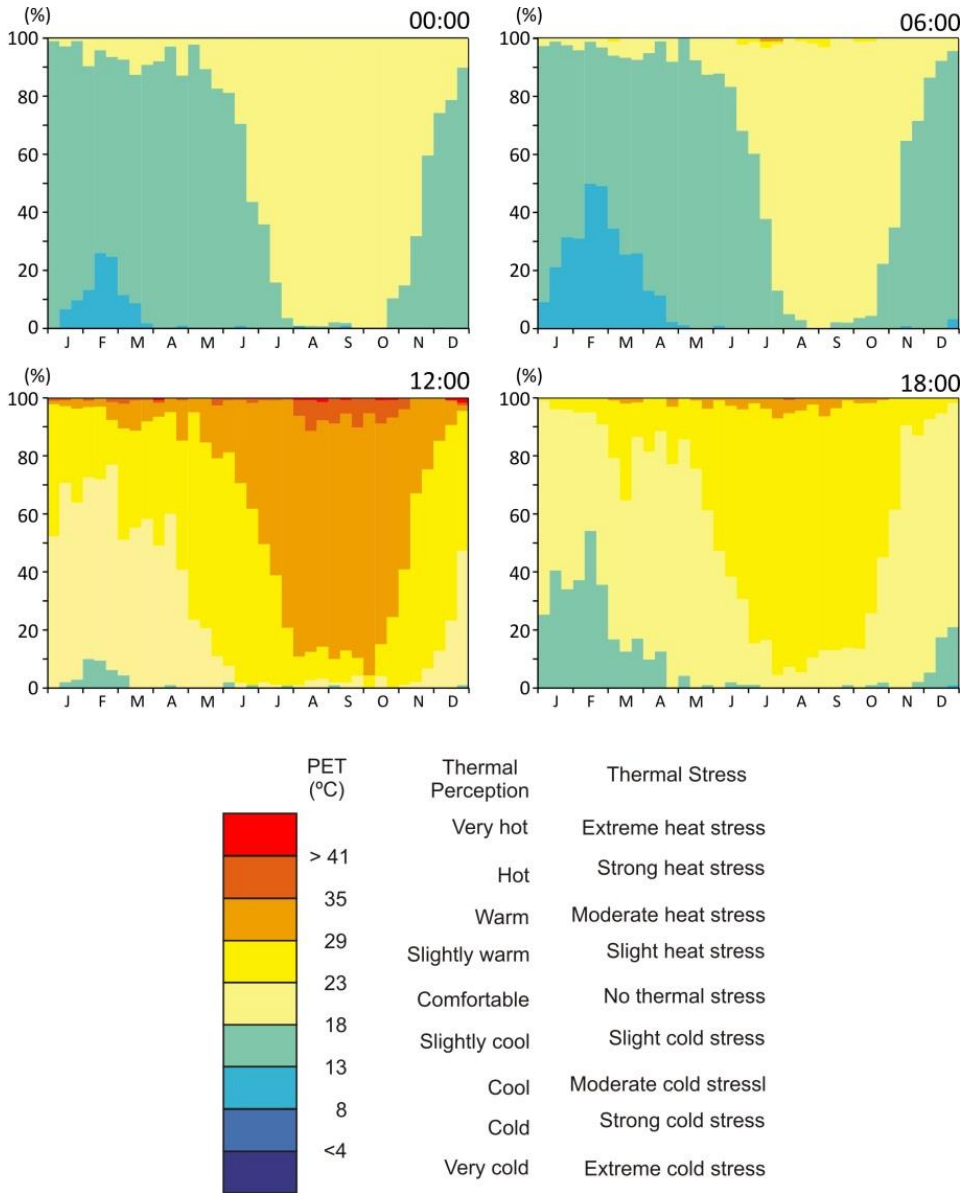


Fig. 5 – Monthly Physiological Equivalent Temperature (PET) between 1998-2006 and 2008-2012 (Praia/Airport meteorological station).

*Fig. 5 – Temperatura Fisiológica Equivalente (PET) mensal entre 1998-2006 e 2008-2012, na estação meteorológica da Praia/Aeroporto.*

## 2. Thermal comfort and heat stress in the “planned” neighbourhood of Palmarejo

In this tropical region, thermal comfort is affected especially by solar radiation, air temperature and ventilation. Due to the high position of the sun in August at 12:00h, the pattern of Mean Radiant Temperature of the surfaces in the Palmarejo neighbourhood (fig. 6) is quite uniform (between 320K and 330K), except for the asphalted roads ( $> 330\text{K}$ ) and shaded areas in the streets ( $< 297\text{K}$ ). The general NE wind (4.6 m/s at the Praia/Airport), at 2 m above ground, is less intense inside the streets (generally  $< 2$  m/s) than in the more open spaces and W/E oriented streets ( $> 3$  m/s). Therefore, poor ventilation, high Mean Radiant Temperature and air temperature ( $\approx 300$  K) are the main features that influence thermal comfort, that ranges from  $27^\circ\text{C}$  to  $35^\circ\text{C}$  in the sun exposed and poorly ventilated streets (the maximum PET value attains  $38^\circ\text{C}$  in these spaces) and stays below  $27^\circ\text{C}$  in the more ventilated open spaces. According to Matzarakis *et al.* (1999) most of the spaces where PET is greater than  $35^\circ\text{C}$  lead to a “hot” and “very hot” thermal perception, corresponding to a “strong” and even “extreme heat” grade of thermal physiological stress. The open spaces, even with strong MRT but well ventilated correspond to warm with moderate heat stress (PET  $< 35^\circ\text{C}$ ).

As was pointed out by Inocêncio (2012), the thermal comfort in the buildings of Cape Verdean cities can be achieved by optimizing the exposure to the sun trajectory and taking advantage of the prevailing winds, using passive cooling techniques, including natural ventilation and the thermal inertia of more traditional materials. As was shown in the present study, especially during daytime of the rainy season, Praia inhabitants feel a hot and humid sensation that combined with lower wind speeds, create a very strong heat stress (PET ranging from  $29^\circ\text{C}$  to more than  $41^\circ\text{C}$ ) even in the open areas like the airport. During night time people feel some amelioration of thermal stress, especially in the hot and humid season.

In the less ventilated streets of city quarters with no shade or vegetation the heat stress can attain “extremely heat stress” levels, especially during very hot days as was shown in the micrometeorological simulation section. In order to avoid these extreme conditions in the urban environment the new building areas should be planned according to the best practices. Therefore, it is strongly advisable that the main streets should be planned with NE/SW orientation in order to take advantage of the trade winds’ regularity. As was shown by Lopes *et al.* (2011) for the Atlantic subtropical island of Madeira, the best measure to take advantage of sea breezes cooling effect in the areas near the shore, during very hot days, is to avoid the construction of buildings that act as barriers to the air flux from the sea. In addition to good ventilation conditions, another effective way to cool down urban areas is to plant trees as they create shaded areas and promote evapotranspiration. However, each situation should be carefully studied, because trees can obstruct the wind (probably retaining atmospheric pollutants as recent studies have shown, Vos *et al.*, 2013) and can fall over people and assets during windstorms (Lopes *et al.*, 2009).

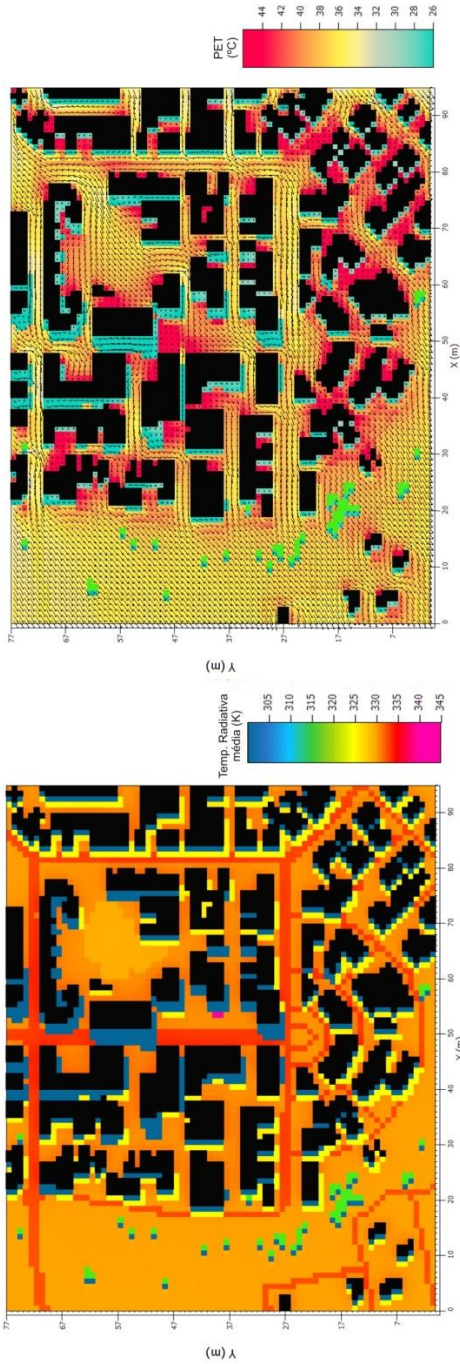
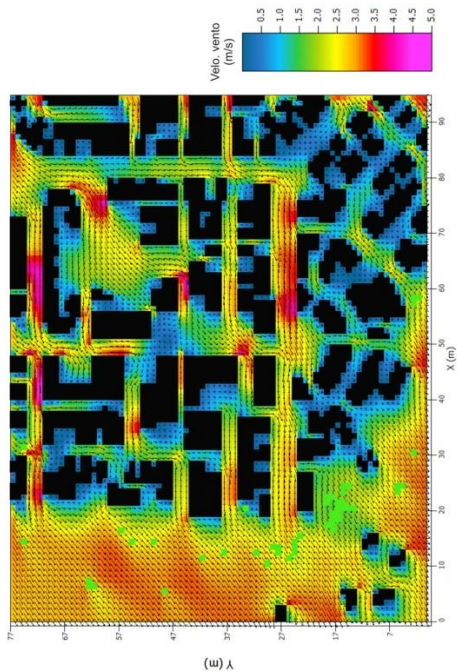


Fig. 6 – Micrometeorological simulation of Mean Radiant Temperature (MRT), wind (speed and direction) and PET (at noon) in Palmarejo, during a warm day (15th August 2012) at 2 m high.

Fig. 6 – Modelação micrometeorológica da Temperatura Radiativa Média (TRM), vento (velocidade e direcção) e PET (a meio de um dia quente) no Palmarejo (15 de Agosto de 2012, a 2 m de altura).



If the heat stress can attain extreme values in the well ventilated neighbourhoods, like the one we studied here, the situation can be even worse in the non-planned “informal” areas, most of them in the bottom of valleys, where most of the poor population live. Urban planning that takes into account the climate conditions is therefore of utmost importance, especially in the most populated areas of the archipelago of Cape Verde.

## V. CONCLUSIONS

This research work is a first attempt to study the urban climate of an African coastal island city and to quantify the thermal stress that city dwellers are submitted to. Although the main research uses PET (Physiological Equivalent Temperature) to assess thermal stress, with classes well tested for European regions, this method was also tested in other African cities. It must be noted that Cape Verde has the advantage of being a well-known touristic destination and that the majority of its tourists originate from European countries. Nevertheless, our intention is to launch inquiries in Cape Verde Islands in the future, in order to adapt thermal sensation classes to the local population.

The first results indicate an extended period of severe heat stress from August to October, especially at noon, when 29°C to more than 40°C is the most common value of PET (more than 90% of the occurrences). Inside the so called “planned” neighbourhoods, like the one studied here (Palmarejo), the heat stress can be “strong” and “extreme”, with PET values exceeding 40°C in the less ventilated streets with little vegetation.

In order to validate 3D modelling and to know more precisely the thermal pattern distribution under thermal stress conditions near the buildings, a low cost urban mesoscale network of thermohygrometers should be implemented, similarly to what has been done in several cities around the world. This will improve our knowledge of the climatic changes in tropical cities.

As long as the lack of fine temporal and spatial resolution meteorological data persists, 3D modelling is a good alternative to obtain results in the microclimatic scale of analysis. Other possibilities (like radiative and sky view factor models) have to be implemented in order to ensure the improvement of urban climate studies in African cities as a tool to cope with future climatic changes.

As the population in these environments becomes more urbanized, urban planning is a fundamental part for the African urban sustainability. As shown by Oliveira *et al.* (2011 and this issue), green spaces in urban areas can create a cooling effect (park cool island) during hot and dry periods in cities with hot climate. Therefore, street trees and green parks (even small ones) providing evapotranspiration and shade, will contribute to mitigate global warming in cities. Furthermore, ventilation strategies, taking advantage of sea breezes and trade wind regularity, must be included in an overall assessment to improve urban environments and alle-

viate the thermal stress during hot period of the year (Lopes, 2009; Lopes *et al.*, 2011). These simple measures can be very useful to diminish the adverse effects of heat in urban areas, and can be easily implemented through proper urban planning as was demonstrated by Alcoforado *et al.* (2005) and Alcoforado *et al.* (2009).

This preliminary analysis of the human bioclimatological assessment in Praia (Santiago Island) highlights the importance to continue with this kind of research, which will include other weather types and atmospheric conditions, namely those with Sahelian origin like the Harmatan and other extreme events.

In the future, new strategies to increment the quality of the urban environment in Praia, along with the creation of a new generation of guidelines for urban planning should be our concern. These guidelines should consider: i) climatic potentialities, like the wind to generate electricity locally to the dwellers (Lopes and Correia, 2012); ii) the risks associated with air pollution and falling elements during windstorms.

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