ANOTHER APPROACH FOR TROPICAL NIGHTS: CASE STUDIES OF FARO, LISBON AND PORTO

Dominic ROYÉ
Universidade de Santiago de Compostela
dominic.roye@usc.es

Abstract

This paper presents a new methodology for the study of hot nights, also called “tropical nights”, in Portugal in order to identify those nights where people can be affected by heat stress. The use of two indicators obtained through half-hourly data has allowed to define in more detail the thermal characteristics of the nights, thereby being able to assess more accurately the risk to the health and well-being of the population. There is a significant increase in the frequency of tropical nights and hot nights on the Atlantic coast, from the north to the south of Portugal. The lower latitude and proximity to the coastline are associated with greater persistence of heat and thermal stress during these nights. The hottest nights are more frequent and intense in the city center due to the effect of the urban heat island.

Keywords: tropical night, heat stress, urban heat island, Portugal.

Resumen

En este trabajo se aplica una metodología nueva al estudio de las noches calurosas, también denominadas “tropicales”, en Portugal de cara a identificar aquellas noches en las que la población pueda verse afectada por estrés térmico. La utilización de dos indicadores obtenidos a través de datos semihorarios ha permitido definir con más detalle las características térmicas de las noches, pudiendo así evaluar con más precisión el riesgo para el bienestar y la salud de la población. Se produce un importante aumento de la frecuencia de noches tropicales y noches cálidas en la fachada atlántica, desde el norte hasta el sur de Portugal. La menor latitud y la proximidad al litoral están relacionados con la mayor persistencia del calor y del estrés térmico durante estas noches. Las noches calurosas son más frecuentes e intensas en el centro de las ciudades, por el efecto de la isla de calor urbana.

Palabras claves: noche tropical, estrés térmico, isla de calor, Portugal.

1. Introduction

Tropical nights are related to summertime and heat waves as a part of our temperate climate in Europe. It is a highly variable phenomena, both temporally and spatially, with significant impacts on citizens. In the last decade a globally significant increase in heat waves has been observed (Coumou and Robinson 2013, Coumou and Rahmstorf 2012). The most significant heat wave for 500 years affected Europe in August 2003 with a very high mortality rate in many of the countries (Coumou and Rahmstorf 2012).

The daily thermal amplitude during a heat wave is a fundamental factor, since it is related to the vulnerability of certain population groups at these extremely temperatures. It has been found that there is an increased risk of mortality with low thermal amplitudes (Gritze et al. 2005, Rooney et al. 1995). Consequently, it limits the possibility of getting an overnight break from the high daytime temperatures. Heat wave effects in the population have been described with apparent links between high temperatures and increased morbi-mortality by different authors (Ye et al. 2012, Diaz et al. 2002, 2006, Garcia Herrera et al. 2005, WHO 2004, Huynem et al. 2001).

In France, for example, there were 15,000 heat-related deaths (mostly among the elderly) between 1th and 20thAugust 2003 (Fouillet et al. 2006). In most of the inland and Mediterranean cities temperature reached peaks above 40°C and minimums higher than 20ºC. The latest report of the Working Group II of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014) notes that there is evidence of increased mortality associated with heat and cold in some parts of the world such as Europe, although in the latter case with less effect. Ultimately, there is a likely increase in frequency and intensity of extreme heat episodes due to global warming.

The IPCC also highlighted as very probable that hot days and nights will be more numerous and even warmer, and not always associated with heat waves. During these days, the effects perceived by the population are caused by extremes temperatures, as well as the corresponding difference between the maximum and the minimum. The most common impact of hot nights on health is their effects on people's sleep and rest. The heat can lead, among other effects, to sleep alterations and privations due to thermoregulation processes (Buguet 2007). Specifically, temperatures higher than the comfort range can influence in an increased wakefulness and decrease phases of Rapid Eye Movement (REM) and Slow-Wave Sleep (SWS) (Haskella et al. 1981, Okamoto and Mizuno 2005).

Sleep alterations are given with greater incidence in people with advanced age, like the overall risk of death in heat waves (Buguet 2007, Köppe et al. 2004). However, it must be considered that not only the temperature is causing these negative impacts, but that also exist influences by humidity and other atmospheric elements, and other environmental variables, such as noise or electromagnetic fields (Muzet 2007). Obviously, one should not exclude in these types of analyzes other social and personal determinants. A possible thermal stress depends, first, on the type of bed or/and bed linen, and secondly, among other things, on the building construction, that is, ventilation, the orientation of the house, material types and the heat conduction between interior and exterior (Höppe and Martinac 1998). In case of presence of air conditioners, there is a close correlation between atmospheric factors and quality of sleep prevailing a socioeconomic origin, as shown by O'Neill et al. (2005) for several US cities.

Precisely in cities the negative impacts of heat on human thermal comfort and, at last, on health are aggravated due to the phenomena of “urban heat island". Higher temperatures in the urban environment than in the rural setting are favored by many factors (Moreno 1999, Lopez et al. 1993). This urban effect become apparent in a slower heat loss in contrast with the surrounding, and generates during heat waves conditions with greater thermal stress and an increased health risk for the citizens.

Given the climate change projections, in which a higher frequency, duration and intensity of heatwaves for Europe is estimated, with major impacts on the Iberian Peninsula and the Mediterranean (Fischer and Schär 2010, IPCC 2014), it is of interest to have adequate indicators for assessing the risk of the nocturnal heat impact on population’s health and welfare. Therefore, the aim of this study is to apply a new methodology to quantify hot nights (also called "tropical") in Portugal in order to identify those nights where people can be affected by thermal stress.

2. The concept of tropical night

The concept of "tropical night" is defined as a night when the minimum temperature is greater than or equal to 20°C (Vincent et al. 2005, Alexander et al. 2006, WMO 2009, EEA Report 2012, Donat et al. 2013, DWD 2013). The expert team on Climate Change Detection and Indices makes use of tropical nights as one of the climatic indicators for monitoring climate change (Lisa et al. 2009, Russo and Sterl 2011). It is a threshold index, which belongs to a group of indices such as frost days or days with precipitation. In these kinds of indices the thresholds are set to identify the days in which these are reached. As a consequence of fixed thresholds, these cannot be evenly valid for all climate zones (Alexander et al. 2006). For tropical nights it is evident that the threshold of 20°C may be useful in Europe, but for tropical climates with higher minimum temperatures for several months it would be questionable. An illustrative example regarding this problem can be seen on the website of the Meteorological Service of Hong Kong (Hong Kong Observatory 2012). First, they call it "hot night" instead of "tropical night"; and, secondly, it is defined with a threshold of 28°C. Even in a study on the biometeorological effects of night temperatures of Athens (Nastos and Matzarakis 2008), a minimum temperature of 23°C was used as a threshold. The mention of "tropical" is ultimately a reference to an unusual situation for extratropical regions, such as Europe.

It has been observed that the exclusive use of the minimum temperature as a reference to delimit the tropical nights may be insufficient to obtain a detailed image of the nocturnal heat impact on human health (Royé and Martí 2015). On the one hand it must be considered that the minimum temperature is usually reached near sunrise (Fig. 1); on the other hand, despite a final record below 20°C, for many hours of the night temperatures can be recorded above 20°C. In addition, there may be days with minimum temperature ranging in the time slot between 23:00 and 24:00. In this case it can be observed that the minimum represent an erroneous assignment for the day, because of higher air temperatures in all previous hours. In Porto 9% of the minimum is reached in that time slot.

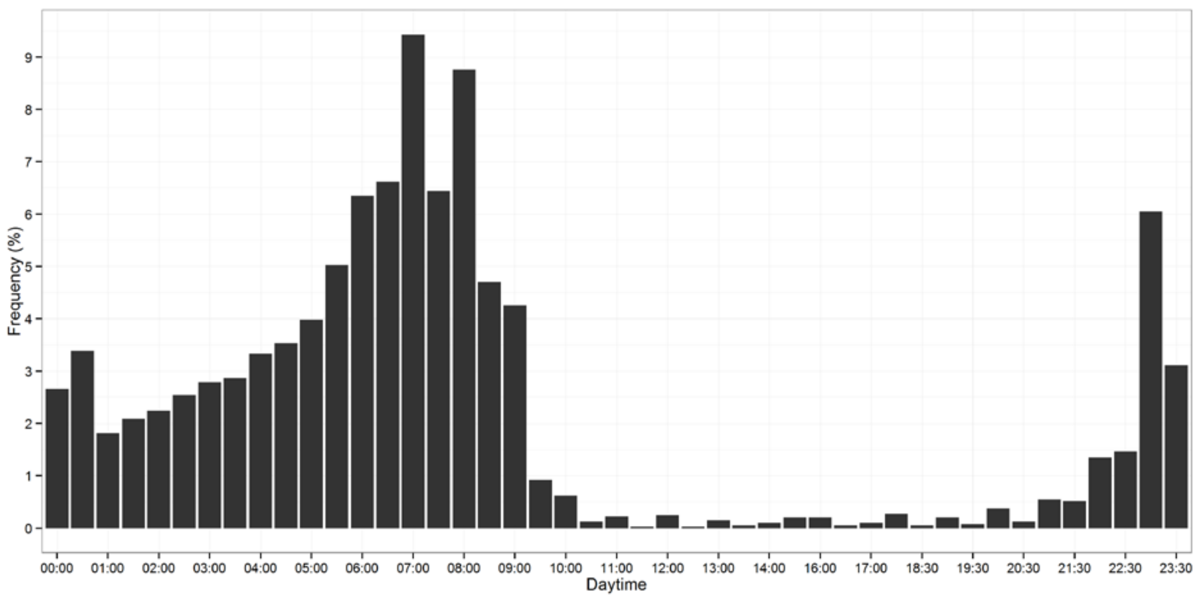

Fig. 1 – Frequency of time slot for minimum temperatures in Porto (2003-2013).

In these described cases the thermal stress is not necessarily less than in the days with a minimum temperature above 20°C. Especially, if one considers that the initial stage of sleep, compared with the following, is described as the most sensitive and can show major alterations due to an accumulating effect of heat stress (Okamoto et al. 2005, 2012). These authors demonstrate the importance of the thermal comfort in the first hours of the night for the sleep during subsequent phases.

These limitations in the use of the low temperature as an indicator of nights with heat stress risk led the authors Royé and Martí (2015) to develop and propose two new indicators in order to improve the evaluation of this type of human thermal stress. In Europe, studies predict an increase in hot and tropical nights because of increased heat waves, as already noted in recent decades (WMO 2009, EEA Report 2012, Olcina 2012, Donat et al. 2013). This is what this study makes particularly important, as it relates to human health.

3. Data and Methodology

The study area corresponds to the Portuguese Atlantic coast, from Porto to Faro (Fig. 2). In this way the relationship between the occurrence of hot nights and latitude can be analyzed, always keeping the Atlantic Ocean as a common geographic factor.

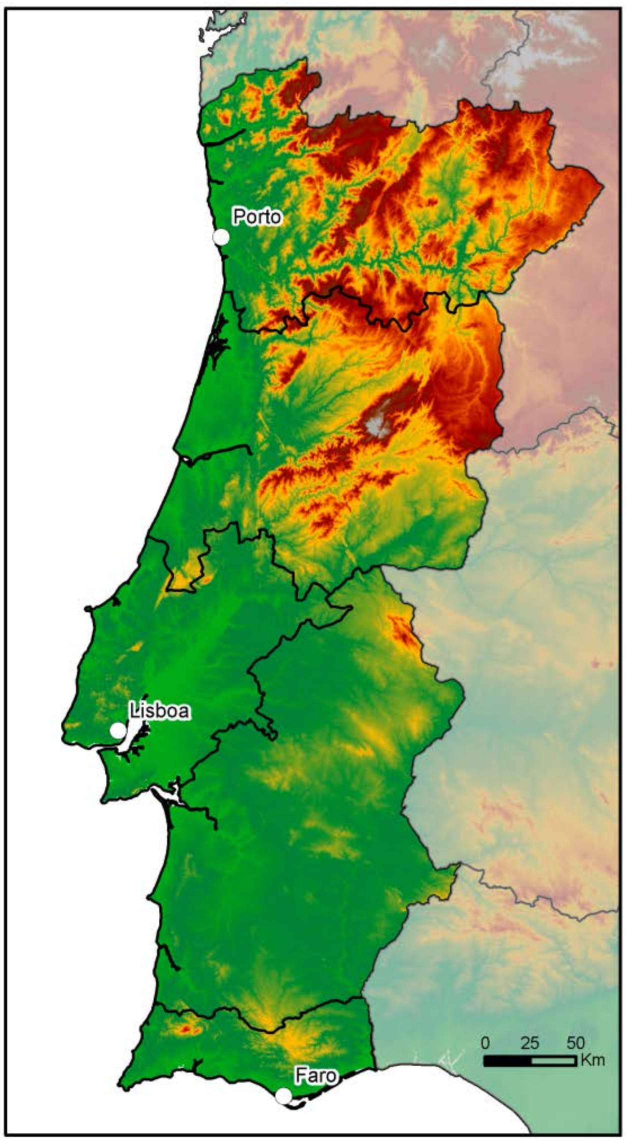

Fig 2 – Study area and weather stations.

From the Integrated Surface Hourly (ISH) Dataset, available at the National Oceanic & Atmospheric Administration (NOAA), were obtained the half-hourly air temperature of Porto, Lisbon and Faro for the period 2003-2013.In all temperature series of the study area the gaps have been less than 2% of total measurements.

In order to use those indicators proposed by Royé and Martí (2015) it is necessary to have at least hourly data from air temperature.

- The first indicator is calculated by the sum of the number of hours during the night in which the threshold of 20°C is exceeded. Subsequently, the value obtained is divided by the total number of night hours to compare different nights of the year (quantified as percentage). In this manner, it is possible to get the number of nights of which the percentage of hours is equal or above 40% (called here "warm night", to distinguish them from the tropical nights in which the proportion is 100% of the night hours with a temperature exceeding the threshold of 20°C.
- The second is an index that allows assessing the intensity of nocturnal heat stress. It is obtained through the sum of the degrees Celsius values during the time, exceeding the threshold of 20°C, and then divided by the total duration of the night (quantified as degrees sums).

In both indices the night is defined as the time period between sunset and sunrise. All the required calculation process was done with the statistical environment "R" (3.2.1). To calculate the variation of the number of hours between sunset and sunrise, it was used the Sun-methods of the *{maptools}* package, which itself has implanted an algorithm of NOAA.

4. Results

4.1. Frequency of warm and tropical nights

The results in Table 1 verify the important difference between the number of tropical nights and warm nights, as defined in the preceding section. The first highlighted fact is the low average of tropical nights in the city of Porto, the northernmost. The increasing number of warm and tropical nights associated with latitude can be seen, clearly. However, it must be underlined, that these tropical nights are a phenomenon characterized by a high temporal variability, as seen in Figure 3. The figure represents the evolution of the number of tropical nights in Lisbon between 1900 and 2013. A strong interannual irregularity can be observed, records in certain years with more than 35 tropical nights, linked to extremely hot summers like 1926 and, above all, the one in 2003, when the intense heat wave in August killed thousands across Europe. These years with very hot summers alternate with years in which there have been significantly less tropical nights. It is also possible to identify in Figure 3 a significant trend of increasing number of tropical nights from the sixties, which would clearly be a footprint of global warming.

Like many extreme weather events, the high interannual variability is one of the most important characteristics, which is often masked by mean values. Thus, it is a more complex reality, and in these cases, some extreme episodes of risk, irregularly shaped, can seriously affect the population's welfare and health.

It is important to consider the behavior of coastal areas, where daily temperature fluctuations, especially during the summer months, are much milder than in the inland, as a result of the regulatory effect of the ocean. However, the effect of latitude and hence the predominance of warm subtropical air masses, are crucial in increasing heat stress risk associated with tropical and warm nights. As one descends along the Atlantic coast the number of warm nights increased steadily and rapidly (Table 1). Thereby, the frequency in Porto is 6.8 and 14.6 for warm and tropical nights, respectively. In Lisbon a strong rise occurs, with 35.2 and 72 nights, which continues to Faro where 70 and 112.2 nights are recorded.

Table1: Annual means of warm and tropical nights 2003-2013

	Warm nights	Tropical nights
Faro	112.2	70
Lisbon	72	35.2
Porto	14.6	6.8

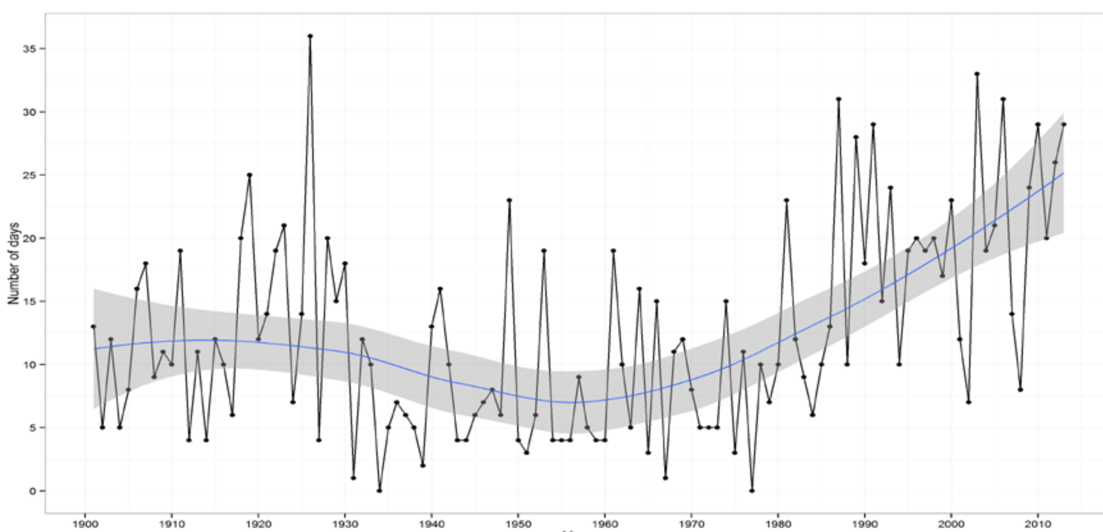

Fig 3 – Trend of tropical nights in Lisbon 1900-2013

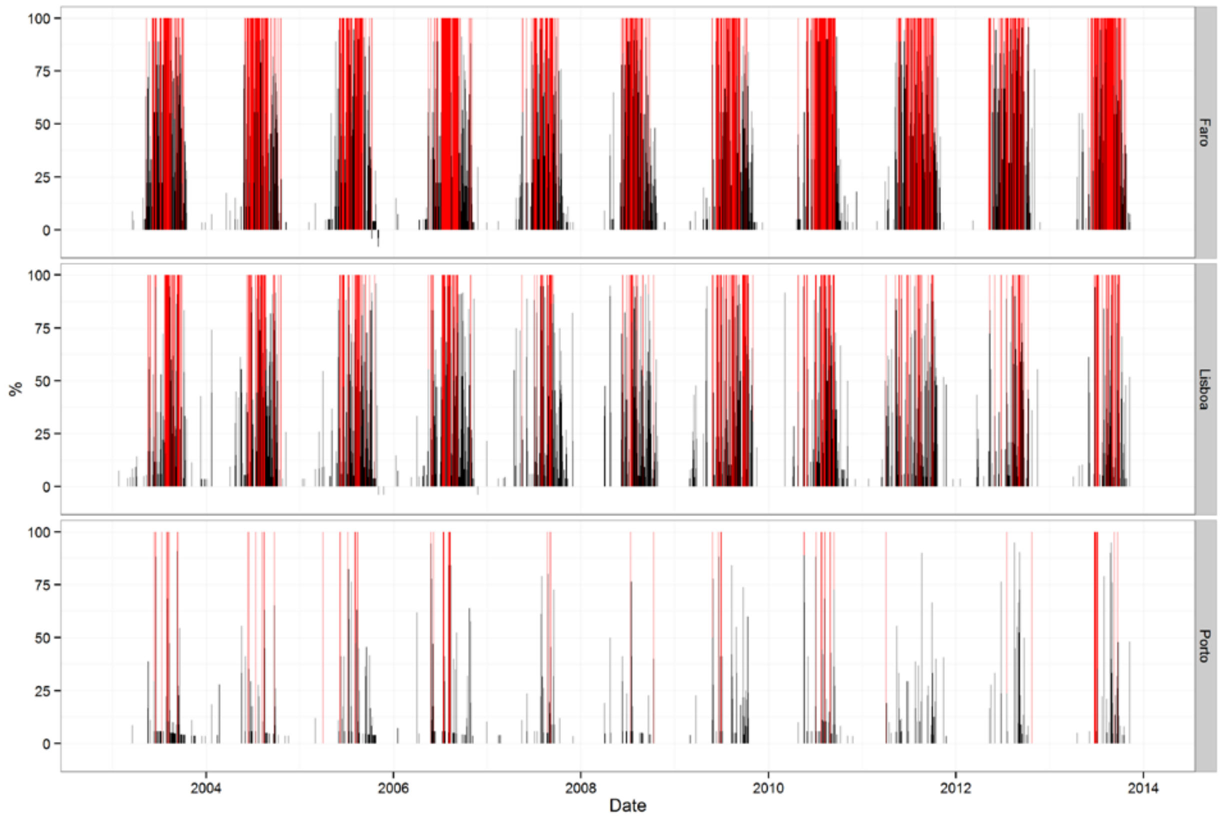

Fig 4 – Proportions of hours (Ta ≥ 20°) in Faro, Lisbon and Porto 2003-2013 (red: night with 100% of hours ≥ 20°C, that is, tropical night in the strict sense)

The observations of tropical nights can be viewed in Figure 4, in which the proportions of hours (Ta ≥ 20°) are visualized for the entire time series. First, a high interannual variability is identifiable and second a significant increase in the number of warm hours, corresponding with latitude (Porto < Lisbon < Faro).

Concerning the months with increased risk of hot nights, they are concentrated between June and September, but the months of July and August are those with a greater number (Figure 4). However, the more a city is located south, the greater may be the dispersion outside of the summer months. It is in these months when more frequently occur atmospheric conditions of stability, in addition to advection of warm air mass from the inland of the Iberian Peninsula or North Africa, which tend to generate heat waves (Gomez-Gesteira et al. 2011, Marti et al. 2011, Lorenzo et al. 2008).

3.2. The persistence of the night heat

In the boxplot in Figure 5 is shown the concentration and dispersion of the warm nights by the percentage of night hours in which temperature exceeded 20°C. From north to south, the dispersion experienced a continuous descent and by opposite the local concentration increases. In the case of Faro and Lisbon almost half of the nights are concentrated in the top of the median, with medians located at 83% and 48%, respectively. Consequently, in Lisbon for example, half of the nights are characterized by registering temperatures above 20°C for more than 49% of the hours. However, in Faro almost over a half of the nights is tropical, with a median of 83%. Consistently, the medians are descending towards the north, so Porto has a median of 10%. However, in Porto, and in most northern cities (Royé and Martí 2015), begin to concentrate a large number of warm nights in the extreme opposite durations, or very low or very high. The explanation could be found in the fact that the northwest of the Iberian Peninsula is affected less frequently by air masses of very hot air, but when they reach latitudes far north, it is associated with episodes of intense heat that favor anomalously warm nights, many of them tropical. While in most southern regions with higher average minimum temperatures in summer months it is not necessary that such extreme episodes occur to have warm and tropical events.

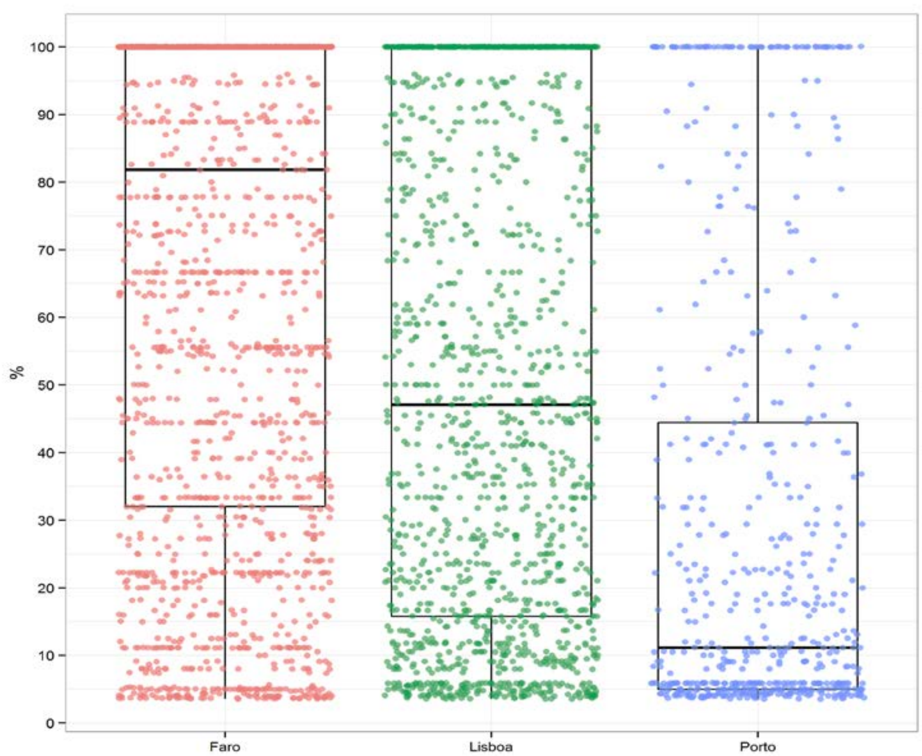

Fig 5 – Distribution of the proportions of hours (Ta ≥ 20°) in Porto, Lisbon and Faro (2003-2013)

3.3. The intensity of warm nights

In order to evaluate the intensity of heat during warm nights there has been used an index obtained by the sum of the half-hourly temperatures during the night period with equal or superior temperatures to 20ºC, and then divided by the total length of the night (due to comparability). The thermal intensity (Figure 6) shows also increases with latitude (Porto < Lisbon < Faro). In Lisbon the most frequent intensities are those between 40° and 55°. In contrast, in Porto and Lisbon they are concentrated at values less than 20º, but Lisbon shows a lower second maximum between 45° and 52°.

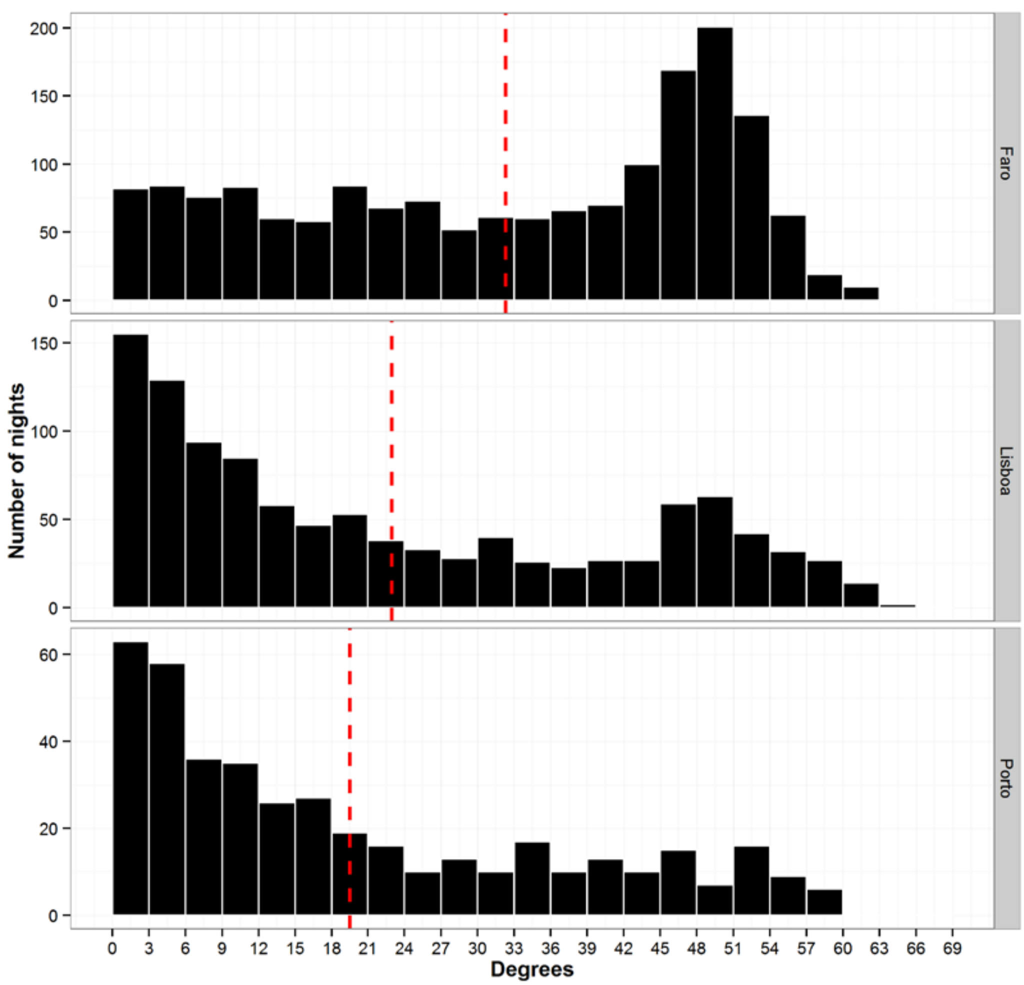

Fig. 6 – Frequency of intensities (degrees) in Porto, Lisbon and Faro (2003-2013)

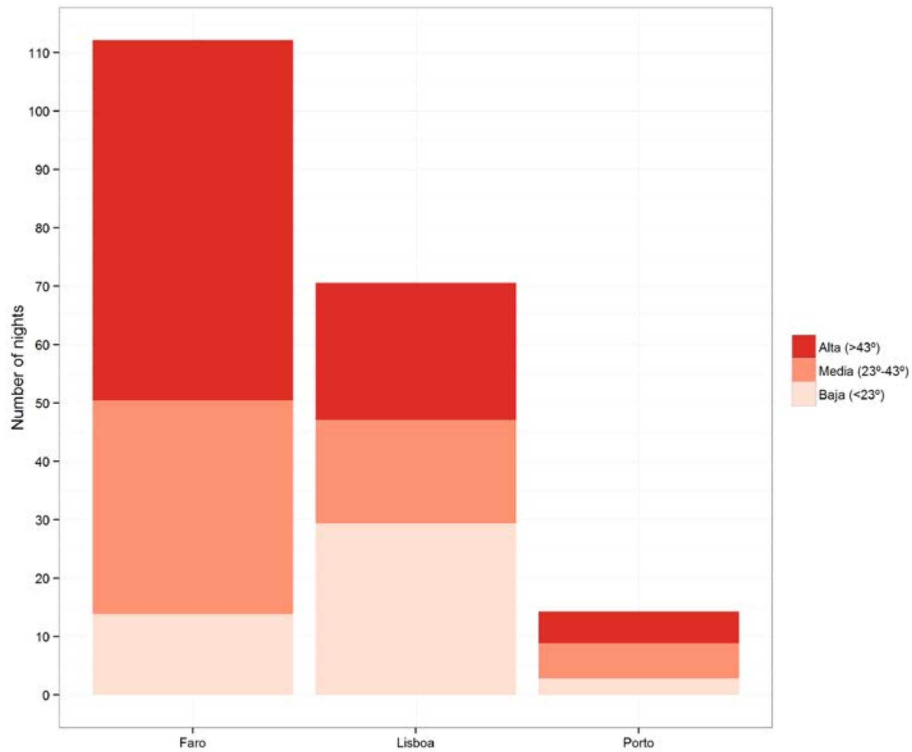

Fig 7 – Frequency of warm nights depending on its intensity (degrees) in Porto, Lisbon and Faro (2003-2013)

For a better understanding, in Figure 7 the thermal intensity distribution of warm nights is represented according to three intensity levels. The nights with a low heat intensity index would be those below 23º, equivalent to approximately a nighttime average temperature less than 21°C; nights with a heat intensity corresponding index between 23º and 43º, equivalent to approximately temperatures between 21ºC and 23ºC; and finally, the high heat intensity, with an index greater than 43º, which would be characterized by having average temperatures greater than 23ºC at night.

First, the significant difference between Porto and the two southern cities, Lisbon and Faro, are highlighted, which is clearly due to the factor of latitude. Second, the proportions of thermal intensities, in the case of Porto over 2/3 corresponding to medium and high intensity, show and confirm the explanations on the occurrence of warm and tropical nights related to heat wave episodes.

Third, in Faro it can be identified that 50% of the warm nights are characterized by high intensities. The geographic location of Faro, protected from direct winds originated in the Atlantic and the greater proximity to the Mediterranean, favors higher intensities and frequencies of warm and tropical nights. Overall, Faro shows warm nights with medium and high intensities in 85% of the days of these characteristics. However, in Lisbon, the warm nights are distributed by a third of high and one third of low thermal intensities. This feature is probably related to increased exposure to the Atlantic.

Intensities and frequencies of warm nights increase significantly in the urban environment. As is known by the abundant scientific literature, cities are sources of heat generated by various local environmental factors, and thereby show a modified thermal structure of the atmosphere above them (Lopez Gomez et al.1993, Fernandez et al. 1998, Brown 1999). Responsible for this effect is that cities conserve more easily the generated heat as an island compared to its surroundings, especially at night. For example, there are factors like urban materials with higher heat capacity, the complex spatial city network and decreased Sky View Factor, anthropogenic heat or light, decrease evapotranspiration, increased sensible heat flux, air pollution and the local greenhouse effect.

However, when assessing the heat stress risk of nocturnal heat for the population, it is necessary to take into account the significant changes of the urban climate on the used indicators, as it is in this case of warm and tropical nights. Furthermore, it must be taken into account that most of the urban weather stations are located on the city's outskirts, where local environmental factors behave differently from the center.

5. Conclusions

By applying the new method it has been possible to show that a significant number of nights with thermal stress, in the first half of the night, are hidden if the minimum temperature as an indicator is used. The same results have been reached in the study by Royé and Martí (2015) for Galicia (Spain). The use of sub-hourly data can assess with greater temporal resolution the thermal characteristics of nights, being able to more accurately evaluate the risks on human welfare and health. It should be borne in mind, however, that the first hours of the night and so also the first sleep phase is described as the most sensitive, and can accumulate major alterations due to heat stress.

The analysis results have confirmed a continued increase in the frequency of tropical and warm nights in the Iberian Atlantic coast, from north to south of Portugal. The lower latitude and the proximity to the coast are directly related to the greater persistence of heat and thermal stress during hot nights. In more continental areas, there may are more often warm nights, however, the persistence of heat is lower due to faster heat loss (Royé and Martí 2015).

Northern Portugal is affected less frequently by hot air masses, but when they reach northern latitudes, as they normally do in combination with intense heat waves, that favor anomalously warm nights, many of them directly of the tropical type. While in more southern regions, with a significantly higher mean minimum temperature, this is not necessary for the occurrence of warm and tropical nights.

The configuration and intensity of heat islands formed in the inner cities do not always coincide with these values collected at weather stations. These usually located in the urban periphery do not correspond to the real temperatures, which residents can perceive in urban centers. Therefore, warm nights probably are more frequent and intense in the inner city, thus its inhabitants suffer higher thermal sensations of stress with consequences for their health. This requires further work in accordance with this fact, to quantify more precisely the effects of heat islands on the frequency, intensity and persistence of warm nights in the urban environment.

6. References

ALEXANDER L. V. et al (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, 111, D05109.

BUGUET A. (2007). Sleep under extreme environments: Effects of heat and cold exposure, altitude, hyperbaric pressure and microgravity in space. *Journal of the Neurological Sciences*, 262, 145-152.

COUMOU D. AND RAHMSTORF S. (2012). A decade of weather extremes. *Nature Climate Change,* 2, 491-496.

COUMOU D. AND ROBINSON A. (2013). Historic and future increase in the global land area affected by monthly heat extremes. *Environmental Research Lett*ers, 8, 034018.

DÍAZ, J. (2006). Impact of extreme temperatures in daily mortality in Madrid between 45 and 64*. International Journal of Biometeorology*, 50, 342-356.

DÍAZ, J. (2002). Heat waves in Madrid, 1986-1997: effects on the health of the elderly. *Int. Arch. Occup. Envirnonment Health*, 75, 163-175.

DONAT, M.G. *et al.*(2013). Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century. *Journal of Geophysical Research: Atmospheres*, 118, 1-16.

DWD (2013). Deutscher Wetterdienst - Wetterlexikon (German Service of Meteorology – weather encyclopedia),http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop?_nfpb=true&_pageLabel=dwdwww_menu2_wetterlexikon&_nfls=false, 25/09/2013.

EEA Report (2012). *Urban adaptation to climate change in Europe: Challenges and opportunities for cities together with supportive national and European policies*, Nr 2, Copenhagen: European Environment Agency.

FERNÁNDEZ, F., GALÁN, E., CAÑADA, R. (Eds.) (1998). *Clima y ambiente urbano en ciudades ibéricas e iberoamericanas*. Ed. Parteluz, Madrid, p. 606.

FISCHER E. M. AND SCHÄR C. (2010). Consistent geographical patterns of changes in high-impact European heatwaves. *Nature Geoscience*, 3, 398-403.

FOUILLET, A.. et al (2006). Excess mortality related to the August 2003 heat wave in France. *Int Arch Occup Environ Health*, 80, 16-24.

GARCÍA HERRERA, R. (2005). Extreme summer temperatures in Iberia: health impacts and associated synoptic conditions. *Annals of Geophysics*, 23, 239-250.

GÓMEZ-GESTEIRA M., GIMENO L., de CASTRO M., LORENZO M. N., ALVAREZ I., NIETO R., TABOADAJ. J., CRESPO A. J. C., RAMOS A. M., IGLESIAS I., GÓMEZ GESTEIRA J. L., SANTO F. E., BARRIOPEDRO D. & TRIGO I. F. (2011). The state of climate in NW Iberia. *Climate Research*, 48, 109-144.

HASKELLA E.H., PALCAA J.W., WALKERA J.M., BERGERA R.J., HELLERA H.C. (1981). The effects of high and low ambient temperatures on human sleep stages. *Electroencephalography and Clinical Neurophysiology*, 51, 494-501.

HONG KONG OBSERVATORY (2012). http://www.hko.gov.hk/cis/regione.htm, 25/09/2013.

HÖPPE P. AND MARTINAC I. (1998). Indoor climate and air quality. Review of current and future topics in the field of ISB study group 10. *Int J Biometeorol*, 42, 1-7.

HUYNENM, M. & MARTENS, P. (2001). The impact of heat waves and cold spells on mortality rates in the Dutch population. *Environ Health Perspect*, 109, 463-470.

IPCC (2014). *Impacts, Adaptation and Vulnerability.* Working Group II Contribution to AR5.

KOPPE C., KOVATS S., JENDRITZKY G., MENNE, B. (Ed.) (2004). *Heat-waves: risks and responses*. WHO Regional Office for Europe, p. 30.

LISA, V., TAPPER, N., ZHANG, X., FOWLER, H.J., TEBALDI, C., LYNCH, A. (2009). Climate extremes: progress and future directions. *International Journal of Climatology*, 29, 317-319.

LÓPEz, A., FERNÁNDEZ, F., ARROY, F., MARTIN VIDE, J., CUADRAT, J.M. (1993). *El clima de las ciudades españolas*. Catedra. Madrid, p. 268.

LORENZO, M.N., TABOADA, J., GIMENO, L. (2008). Links between circulation weather types and teleconnection patterns and their influence on precipitation patterns in Galicia (NW Spain). *International Journal of Climatology*, 28, 1493-1505.

MARTÍ, A., CABALAR, M., GARCÍA, E. (2011). Natureza e medio ambiente. En Piñeira, M.J., Santos, X.M. (coords.), *Xeografía de Galicia*. Xerais. Vigo, pp. 99-129.

MARTI, A., MIRAGAYA, A. (1998). Geometría urbana, temperaturas e isla de calor en Santiago de Compostela. En Fernández et al. *Clima y ambiente urbano en ciudades ibéricas e iberoamericanas*. Ed. Parteluz, Madrid. pp. 207-218.

MORENO GARCÍA, M. C. (1999). *Climatología urbana*. Edicions Universitat de Barcelona. p. 71.

MUZET, A. (2007). Environmental noise, sleep and health. *Sleep Medicine Reviews*, 11, 135-142.

NASTOS P. T. AND MATZARAKIS A. (2008). Human-Biometeorological effects on sleep disturbances in Athens, Greece: A Preliminary Evaluation. *Indoor Built Environment*, 17, 535-542.

O'NEILL M. S., ZANOBETTI A., SCHWARTZ J. (2005). Disparities by Race in Heat-Related Mortality in Four US Cities: The Role of Air Conditioning Prevalence, *Journal of Urban Health*, 82, 191-197.

OKAMOTO-MIZUNO K. AND MIZUNO K. (2012). Effects of thermal environment on sleep and circadian rhythm, *Journal of Physiological Anthropology*, 31, 1-14.

OKAMOTO-MIZUNO K., TSUZUKI K., MIZUNO K. (2005). Effects of humid heat exposure in later sleep segments on sleep stages and body temperature in humans. *Int J Biometeorol*, 49, 232-237.

OLCINA, J., MARTIN, D. (2012). Variaciones en la densidad del oxígeno en el aire y su influencia sobre la salud humana. *Boletín de la Asociación de Geógrafos Españoles*, 58, 7-32.

ROONEY C., MCMICHAEL J. A., KOVATS R. S., COLEMAN M. P. (1995). Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. *J. Epidemiol Community Health*, 52, 482-486.

ROYÉ, D., MARTÍ, A., CABALAR, M. (2012). Aproximación al comportamiento espacial del estréstérmico en Galicia a través del uso del índice bioclimático PET. En Rodríguez Pueblа*et al.* (eds) : *Cambioclimático. Extremos e impactos*. Publicaciones de la Asociación Española de Climatología. Serie A, Nº 8. Salamanca, 941-949.

ROYÉ, D. AND MARTÍ, A. (2015). Análisis de las noches tropicales en la fachada Atlántica de la Península Ibérica. Una propuesta metodológica. *Boletín de la Asociación de Geógrafos Españoles*, 69, 351-368.

RUSSO, S. AND STERL, A. (2011). Global changes in indices describing moderate temperature extremes from the daily output of a climate model. *Journal of Geophysical Research: Atmospheres,* 116, 16.

VINCENT, L. A.. et al(2005). Observed Trends in Indices of Daily Temperature Extremes in South America 1960-2000. *AMS Journal of Climate*, 18, 5011-5023.

WHO (2004). *Heat waves: risk and reponses*. Series 2, World Health Organization. Copenhagen.

WMO (2009). *Analysis of extremes in a changing climate in support of informed decisions for adaptation.* World Meteorological Organization. Geneva. WCDMP-No. 72, 52 pp.

YE X., WOLFF R., YU W., VANECKOVA P., PAN X. & TONG, S.(2012). Ambient Temperature and Morbidity: A Review of Epidemiological Evidence.*Environmental Health Perspectives*, 120, 19-28.