Chapter 4
The Bioclimatic (Dis)comfort and Summer Thermal Paroxysms in Continental Portugal: Intensity, Frequency and Spatial Contrasts

Susana Oliveira Moço, José Eduardo Ventura, and Malheiro Ferreira

Abstract The effects of the changing climate system have become increasingly important in recent years, leading to a need to better understand, among other things, what impact they have on population health and human thermal comfort.

This research analyzes the variability of thermal (dis)comfort due to heat in summer, in Continental Portugal, between 1981 and 2010, based on an appropriate set of bioclimatic indicators. It also addresses the prevailing synoptic situations during climate paroxysms, namely heat waves, by applying the Heat Wave Duration Index formula. The synoptic classification used is an adaptation proposed by Ramos (1987).

We conclude that the feelings of discomfort due to heat are quite frequent. Since 2000, the cities of Coimbra and Lisbon have revealed a trend for thermal sensations of greater intensity.

The results show evidence of spatial contrasts, with the north-west of the country being thermally more comfortable.

On the basis of the occurrence of paroxysms, the position of the Atlantic anticyclone is connected, at altitude, with situations of meridian circulation and the dominance of wave regime and blocking.

Here, we intend to contribute to the identification of vulnerable areas and predict intense heat situations, preventing risks to public health and human welfare.

Keywords Climate change • Climate variability • Thermal comfort • Climate vulnerability • Climate risk • Welfare

S.O. Moço (✉) • M. Ferreira
Department of Sciences and Technology, Universidade Aberta, Lisbon, Portugal
e-mail: susana.moco@gmail.com; manuelamalheiro@gmail.com

J.E. Ventura
Department of Sciences and Technology, Universidade Aberta, Lisbon, Portugal

CICS.NOVA Research Centre for Social Sciences, Universidade Nova de Lisboa, Lisbon, Portugal
e-mail: je.ventura@fcsh.unl.pt

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Introduction

The scientific literature reveals concern about the effects of climate system change and increased vulnerability to risks. In this sense, assessments of human thermal comfort should be considered in relation to spatial planning, especially within a context where global climate projections point to a rise in average air temperatures, which can lead to temperature extremes that are adverse for the human health, well-being and quality of life.

This article is based on human bioclimatology treating the problem of discomfort caused by heat during the summer in Portugal and the occurrence of certain paroxysms, in particular, heat waves and associated synoptic causes.

This approach aims to contribute to the knowledge of how frequent this phenomenon is and its possible impacts on a regional scale, thus contributing to improving the population's quality of life in bioclimatic terms.

State of the Art

Scientific studies on the urban climate began in nineteenth century Europe with the Howard's work (1833) on London's climate. Using an analysis of meteorological records for the period between 1797 and 1831, Howard found that air temperature values are often higher in the city than in the rural areas around them. Also in the nineteenth century, Emilien Renou published a work on climate change in Paris, analyzing, besides the temperature problem, the question of ventilation in the city (Landsberg 1981).

In the 1920s Vienna, Wilhelm Schmidt was the first to use the urban transects technique, which uses vehicles to carry out meteorological measurements at different points in urban areas and outskirts. Until then, studies were based on a comparison of data from urban and rural weather stations.

After the Second World War, the growth and expansion of metropolitan and urban areas encouraged studies on urban climate, mainly in the United States, Japan and certain European countries. Important references are the work of Chandler (1985) on the climate of London, of Landsberg (1981), which systematized the main changes in climatic factors in urban areas and that of Oke (1978) on the urban boundary layer. Olgyay (1963) and Givoni (1981) also did research related to climate impact on the built environment and human comfort.

In the late 1960s and early 1970s, researchers involved in climatology turned to outer space, where energy and water balance concepts became central themes. Many of these works were associated with major observation programs that have occurred in American and Russian cities since 1994. The high number of works produced in this period led the World Meteorological Organization (WMO) to sponsor a series of reviews on the subject.

In the last two decades of the twentieth century, methods, research techniques and the monitoring of urban climate were consolidated (Oke 1984), focusing on processes and atmospheric conditions over the city as a base for physical and numerical modeling. During this period, studies of urban climatology in the tropics were still very limited, highlighting those of Jáuregui (2000).

While research in developed countries has been concentrating on physical and numerical modeling, most studies in tropical areas still focuses on a descriptive approach of heat islands and air quality, paying little attention to the energy balance, modeling and development applications for urban planning.

Madrid was the site of numerous climate studies initiated in 1982 by Fernández García and carried out during 1990 and 1996 with special emphasis on pollution and urban climate. López-Gómez and Fernández García (1984) also participated in other studies on urban climate. In Barcelona, important studies were conducted by Carreras et al. (1990) and Clavero (1990), while Valencia had those of Caselles et al. (1992). Later studies were conducted in other Spanish cities.

In Portugal, the first study addressing this issue was conducted by Alcoforado (1988) in the Lisbon region. In 1994, Andrade studied the urban climate and air pollution and, in the same year, Lopes made a study dedicated to topoclimatology, relating land use and its effects on climate. In Coimbra, the study of urban climate (topoclimatology) came about with Ganho (1992). Porto's climate was studied by Monteiro (1993). In 1996, Freire's work about comfort and discomfort develops a bioclimatic classification and the researcher found that there is a very positive correlation between the variation in the bioclimatic comfort and mortality, whether monthly or annual, cardiovascular diseases, respiratory and death by suicide, which was followed by other publications in this area (1997, 1998, 2000, 2005, 2006, 2009a, b). Freire and Vasconcelos' study (2012) and that of Andrade (2004) should also be mentioned.

Studies that relate meteorological variables with health, particularly temperature with health, have gained importance as a contribution to the understanding of the effect of urban environmental change on population health and possible vulnerabilities regarding global climate change, highlighting the influence of extreme events.

In this context, and in relation to heat situations, we have the work of Calado et al. (2003 cited by Silva et al. 2014), which calculates excess deaths associated with the 2003 heat wave; Nogueira and Paixão (2008), which contributed to updating the ICARUS model (Surveillance System for heat waves, since 1999) and to increasing knowledge of the mechanism and impact of heat waves on mortality; (Silva et al. 2014) and Almeida et al. (2010), who discovered that the variation in mortality in Lisbon and Porto during the warmer months of the year, with modeling of the mean apparent temperature and daily mortality during the summer; Monteiro et al. (2013a), who studied the impact of heat waves in the Metropolitan Area of Porto in 2006, and concluded that, during the heat wave, excess mortality from all causes and morbidity was due to respiratory illnesses, pneumonia and chronic obstructive pulmonary disease.

In 2012, Monteiro et al. studied the relationship between episodes of cold and excess of hospitalizations related to Chronic Obstructive Pulmonary Disease (COPD) in the Metropolitan Area of Porto. The authors (Silva et al. 2014) calculated excessive admissions in the period leading up to and following the cold waves, finding that there is a gap of at least 2 weeks between the occurrence of cold waves and increased hospitalizations for COPD patients. They also identified that the persistence of low temperatures (T min $\leq 5\ ^{\circ}\text{C}$) for periods of at least 1 week may be more important to increased COPD morbidity than very low temperatures for very short periods of time (Tmin $\leq 1.6\ ^{\circ}\text{C}$).

Monteiro (2013); Monteiro and Carvalho (2013); Monteiro et al. (2013b, c, d); and Monteiro and Velho (2014) studied climate and health in Porto using a set of bioclimatic indices, including, among others, Physiological Equivalent Temperature and Average Temperature Radiant. In relation to Portugal, Vasconcelos (2012 cited by Silva et al. 2014) studied cold exposure as a risk factor for hospital admissions related to cardiovascular disease, while Vasconcelos et al. (2013) concluded that, in Lisbon and Porto, cold contributes to the increase in daily admissions for myocardial infarction.

In order to minimize the effects of thermal discomfort on people's health, numerous investigations have been developed at academic level that make it possible to identify the contribution of spatial planning to the population's health. This work, due the scale of analysis (mesoscale) and the specificity of the indices used, make an innovative contribution that can be applied to regional planning.

Data and Methodology

Spatial and Temporal Framework

To study the summer bioclimatic variability, weather stations from the Portuguese Meteorological Institute used in the daily weather forecast were selected, as exemplify the country's climatic diversity. The chosen stations were Bragança, Porto, Coimbra, Lisbon, Beja and Faro (Table 4.1 and Fig. 4.1) (Moço 2005).

The analysis of discomfort originated by heat assumes, first, the use of a reference sample at the time this occurs more frequently; i.e. the summer months: June, July, August and September. A 30-year period was considered (1981–2010).

The period considered in the study is 3524 days (97 % of the total days of the selected period and the remaining 3 % correspond to 106 days without or with incomplete records of variables at one or more weather stations).

We used daily data of 06 and 18 UTC, related to climatic variables: wind direction and speed, average, minimum and maximum temperature, and relative humidity published in the Portuguese Meteorological Institute's daily weather forecasts at weather stations considered during the summer periods of 1981–2010 (June, July, August and September).

Table 4.1 Network of weather stations used

Location	LAT (N)	LONG (W)	ALT (m)
Bragança	41°48′	06°44′	690
Porto/P. Rubras	41°14′	08°41′	70
Coimbra/Geophysical	40°12′	08°25′	141
Lisbon/Portela	38°46′	09°08′	123
Beja	38°01′	07°52′	246
Faro/Airport	37°01′	07°58′	8

Source: Climatological Yearbook of Portugal (Moço 2005)

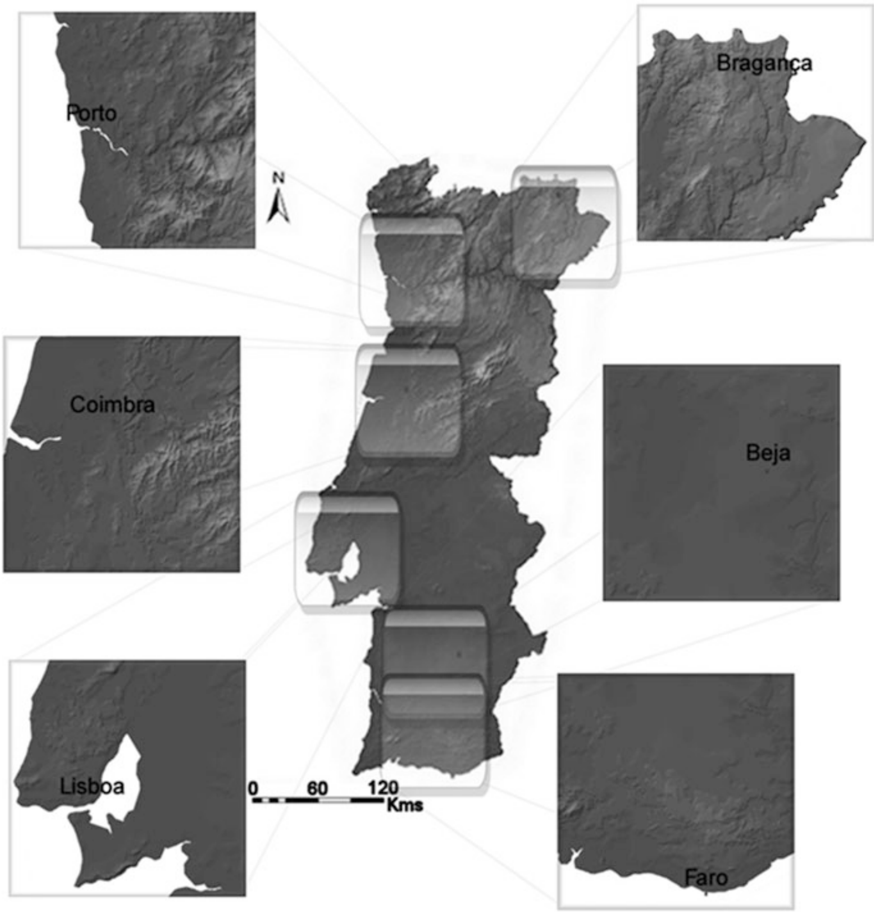

Fig. 4.1 Location of Bragança, Porto, Coimbra, Lisbon, Beja and Faro weather stations [*Source*: Moço (2005)]

Bioclimatic Indexes

In this study, the wide range of indexes selected were those best suited to the objectives of the analysis and best reflected the feelings of discomfort related to heat.

The calculation of the temperature-humidity index (THI) of GILES (Ganho 1998), Effective Temperature (ET) and Equivalent Effective Temperature (EET) of BROOKS, mentioned by BÚTIEVA in 1984 (León et al. 2003) was considered appropriate to achieve the proposed objectives.

The THI index is calculated using the following formula: where T is the air temperature in °C and RH the relative humidity expressed in % (Ganho 1998):

$$THI = T - 0.55\ (1 - 0.01\ \ RH)\ (T - 14.5).$$

Considering that the THI index is a mathematical calculation that, in principle, will be not an integer value (as opposed to actual values), there may be values that are not included in any of the classes in question. As such, a slight adjustment to comfort classes was made:

- <21: absence of discomfort heat
- $\geq 21 < 24$: less or 50 % of the study population expresses feelings of discomfort
- $\geq 24 < 27$: more than 50 % of the population feels discomfort
- $\geq 27 < 29$: most individuals feel discomfort
- $\geq 29 < 32$: all individuals feel strong bioclimatic stress
- ≥ 32: medical emergency

The other ET and EET indicators incorporate the combined effect of temperature and relative humidity (ET), adding the effect of wind (EET) on people with summer clothing, under outdoor conditions, in the shade, performing light physical activity (León et al. 2003). These are empirical indexes, which subjectively evaluate the actual thermal state of individuals. They express the sensation perceived with any combination of the considered variables, which is equal to the feeling one gets with the expressed temperature, with 100 % relative humidity and no wind under controlled conditions (León et al. 2003).

The calculation of these indexes is made from the following expressions:

$$ET = t - \frac{G}{80}\,(0.00439\ T^2 + 0.456\ T + 9.5)$$

$$EET = ET + W\ ((0.11\ T - 0.13) - 0.002TG)$$

Where:

t: air temperature in °C

(continued)

T: t – 37 difference between the air temperature and the human body temperature expressed in °C
W: wind speed at a height of two meters, from the relation 0.67 V, where V corresponds to the wind speed at a height of ten meters, in m/s.
G: 100 – RH
RH: air relative humidity expressed in %

The evaluation of thermal sensations in the case of the results obtained by these two indexes was accomplished through the use of classes (°C) proposed by León et al. (2003) and an approach for the Portuguese case (Moço 2005), resulting in the following classes:

- <22: absence of discomfort heat
- $\geq 22 < 25$: slightly warm
- $\geq 25 < 28$: hot
- ≥ 28: very hot

According to León et al. (2003) and Moço (2005), these classes cover the majority of the population who feel discomfort.

The average monthly performance of the bioclimatic indexes involved was analyzed, as well as the frequency and intensity of heat discomfort at each selected station. The contribution of each climate variable was also discussed for each of the indices by determining the Pearson linear correlation coefficient (add reference). The trend of bioclimatic indices for the period 1981–2010 was determined accordingly.

In the case of heat waves, after the analysis of various indexes, it was considered appropriate to use the following formula (Tank 2002):

$$\text{HWDI}\ (\textit{Heat wave duration index}) = \text{TX}_{ij} > \text{TX}_{inorm} + 5$$

In which TX_{ij} corresponds to the maximum temperature of the day i during the j period and TX_{inorm} corresponds to the maximum average daily temperature corresponding to a 5-day period filter used as reference (1971–00). A heat wave is considered to be happening when the abovementioned conditions occurred for at least 6 consecutive days.

Analysis and Discussion of Bioclimatic Summer Comfort in Portugal

The Influence of Climatic Elements in THI, ET and EET Indexes

To investigate the importance of the temperature, relative humidity and wind speed variables taken at each weather station, according to each of the bioclimatic indexes used, correlation matrices were constructed concerning significance levels between the daily average values of the climatic elements and the comfort indexes in the two time periods (06 and 18 UTC) used in this study.

Thus, the evaluation of the Pearson correlation matrix (Fig. 4.2) for each of the weather stations, which corresponds to the interdependence between the bioclimatic indexes and the variables that compose them, defines their importance in the value of the index and, hence, the variation of thermal sensations.

As you would expect at any weather station, and in any of the bioclimatic indexes, the role of temperature seems more prominent compared to humidity and wind speed in the case of EET.

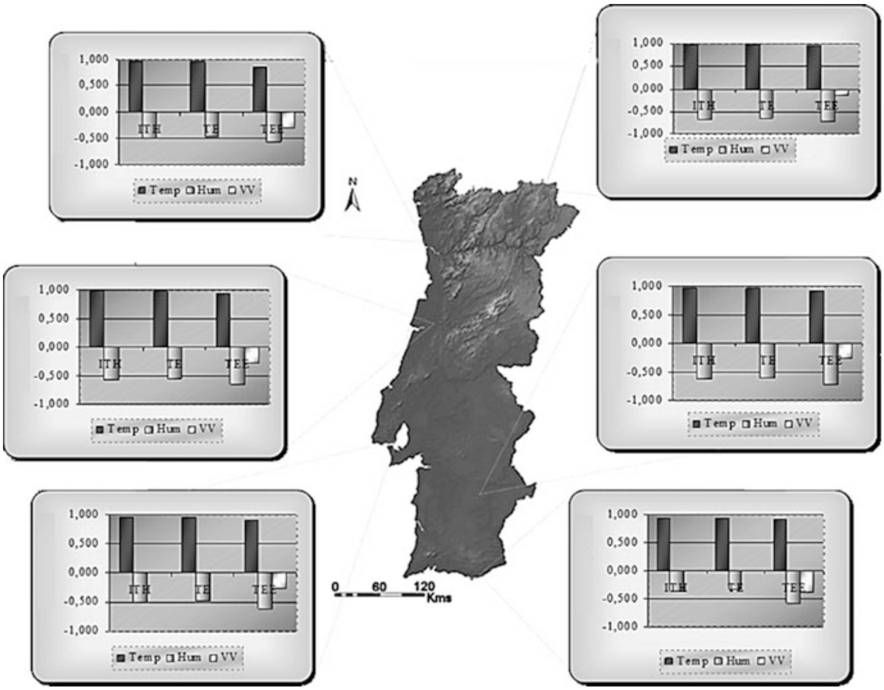

Fig. 4.2 Correlation coefficients (r) between the values obtained by THI (ITH), ET (TE) and EET (TEE) and climatic elements. *Temp* temperature, *Hum* relative humidity, *VV* wind speed (at a height of 2 m)

Temperature variations directly influence sensations of comfort/discomfort. In the case of relative humidity, it appears that thermal comfort varies inversely to this variable. This is justified because of the heat exchanges through evaporation, depending on the outdoor relative humidity—in a very humid environment, evaporation is limited, greatly reducing the potential of the heat dissipation inherent to perspiration and increasing thermal discomfort. Increased relative humidity reduces the capacity for water evaporation and the potential for heat dissipation, the only mechanism that, under particular environmental conditions, is capable of balancing the body heat gains.

In the case of EET, the temperature and humidity variables also have a particular significance in comparison to the role of the wind. Although wind has some cooling power, it is not the most significant variable in the variation of thermal comfort, which explains why the cooling effect of the wind in summer is not as significant as in winter.

Thermal comfort is primarily dependent on temperature; relative humidity and wind reinforce or reduce the sensation given by temperature.

The wind speed of the monthly average values are higher at 18 UTC in all weather stations; however, it has little influence on the index result when compared with temperature and relative humidity.

At the Porto and Faro weather stations, the effect of the wind seems to have more influence on the variation of thermal comfort than at other weather stations. In contrast, was in the weather station of Bragança, where this variable has less significance on the variation of thermal comfort.

The Spatial and Temporal Distribution of the Monthly Values of THI, ET and EET

The examination of Figs. 4.3 and 4.4 show that, at any of the weather stations, bioclimatic average values translated by THI and ET indexes are always higher compared to the average values of the thermal sensation translated by EET during the period of the sample.

The conclusion is that with decreasing latitude there is a tendency for situations to be more thermally uncomfortable.

Examination of the monthly mean values of bioclimatic indexes at 18 UTC (Fig. 4.4 and Table 4.2) at the Coimbra, Lisbon, Beja and Faro weather stations shows that, according to THI, thermal sensations fall into the class ranging between 21 and 23.9, where 50 % of the study population expresses feelings of discomfort. The situation is similar for the ET index, where the values obtained correspond to slightly warm thermal sensations. The Porto and Bragança weather stations boast greatest latitude and are less exposed to tropical high pressure that advance north at this time of year and influence our mainland, especially the most southern latitudes

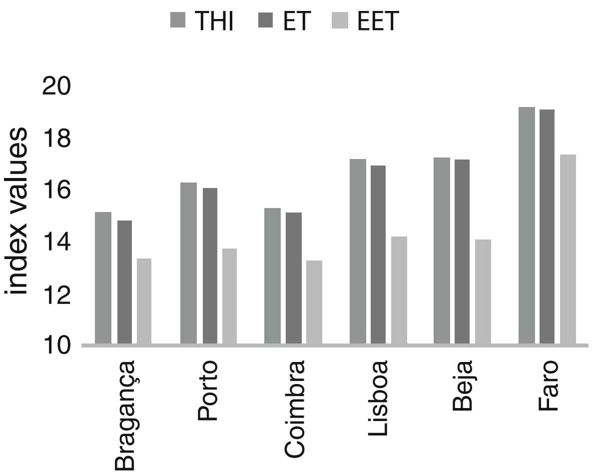

Fig. 4.3 Average monthly values of THI, ET and EET in the summer months during the period 1981–2010 at 06 UTC

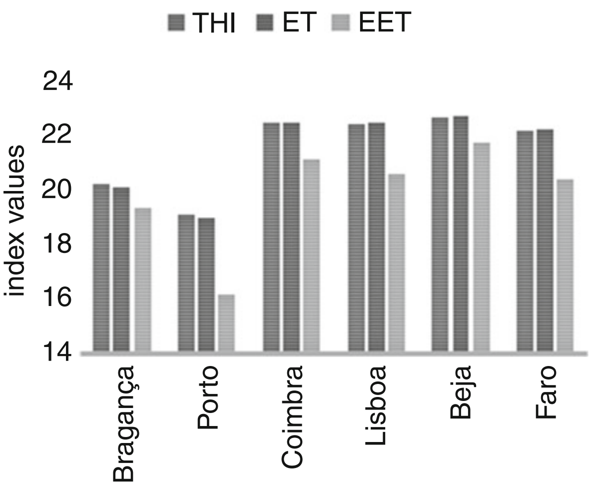

Fig. 4.4 Average monthly values of THI, ET and EET in the summer months during the period 1981–2010 at 18 UTC

(Table 4.2). In Bragança, it is worth highlighting the altitude at which the weather station is located.

Considering the average values of EET, Beja weather station shows slightly warm thermal sensations, resulting from the combined effect of latitude and continentality, being located in a sheltered position in relation to the sea breezes and north winds.

Any of the bioclimatic indexes used indicate lower values (more thermally comfortable) in June and September, both at 06 UTC and 18 UTC. The months of July and August, with average values of higher temperature, show higher values in the three indexes (Fig. 4.5).

Table 4.2 Total average of indexes at 18 UTC

Average 18 UTC	THI	ET	EET
Bragança	20.2	20.1	19.4
Porto	19.1	19.0	16.2
Coimbra	22.5	22.5	21.1
Lisbon	22.4	22.4	20.5
Beja	22.6	22.7	21.7
Faro	22.2	22.2	20.4

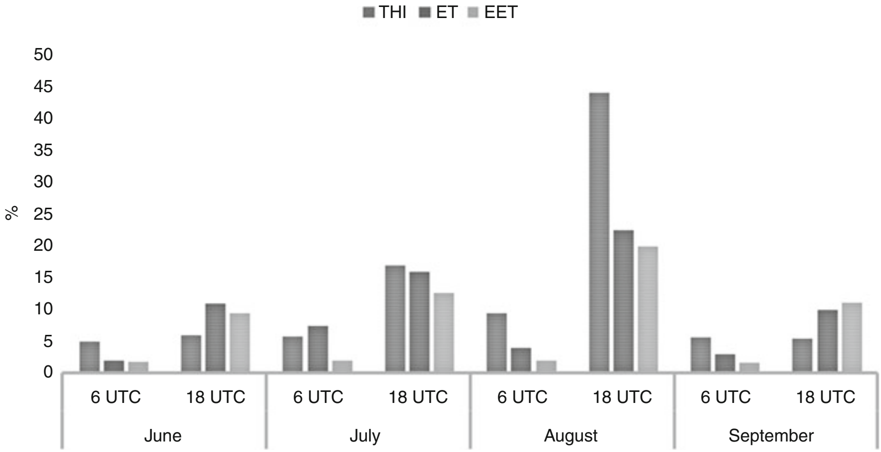

Fig. 4.5 Total percentage of days with discomfort in the summer months during the period 1981–2010

In this sense, without devaluing the role of relative humidity or wind speed, in the case of EET index, the values obtained from the bioclimatic indexes seem to change more closely in line with air temperature values.

The temporal distribution of annual average indexes values (Figs. 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, and 4.17) shows an intra and inter annual irregularity of values of thermal sensation in the two time periods. THI and ET years 1981 to 1990, 1998, 2000, 2003, 2004, 2009 and 2010 show the highest average values at most weather stations.

The examination of the trend lines at 06 UTC (Figs. 4.6, 4.7, 4.8, 4.9, 4.10, and 4.11) denotes an increase, albeit not a significant one, of the thermal sensations at all the weather stations, with the exception of Coimbra, which shows a decrease, and Lisbon, which boasts a relatively constant tendency to increase. Matching the results obtained with the global climate models, there may be some parallels pointing towards an increase in thermal sensations, along with the forecasts for the rise in global temperature. However, in view of the above, and given the natural decline in temperature at night in Coimbra, there is a tendency for reduced feelings of discomfort related to heat. As such, there is a tendency for more thermally comfortable situations, which may be indicative of a strong degree of urbanization,

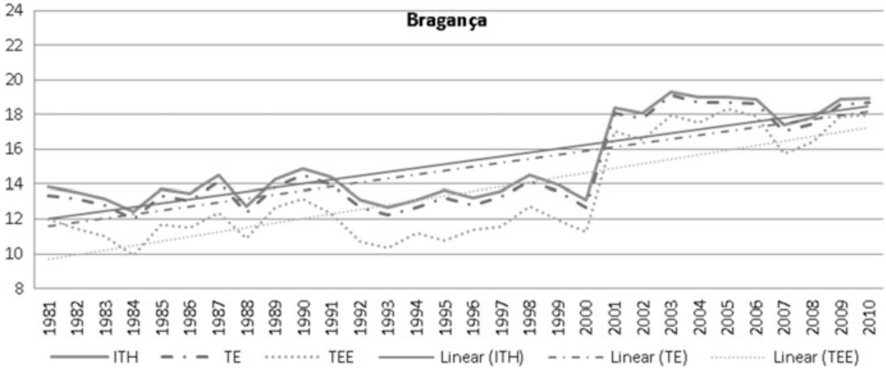

Fig. 4.6 Temporal evolution and linear trend of average annual values of THI, ET and EET at 06 UTC in Bragança during the summer period (1981–2010)

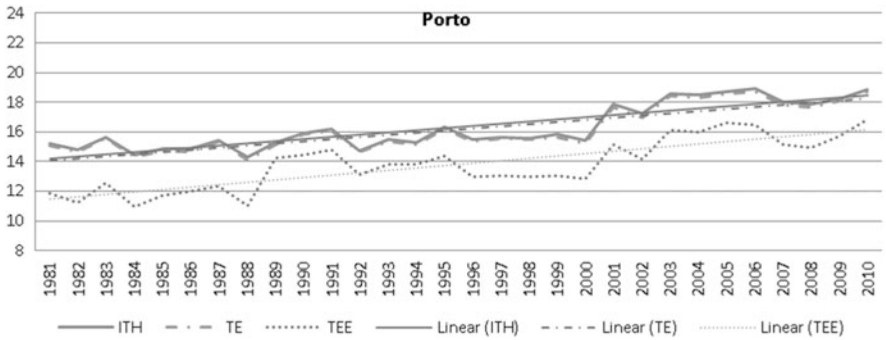

Fig. 4.7 Temporal evolution and linear trend of average annual values of THI, ET and EET at 06 UTC in Porto during the summer period (1981–2010)

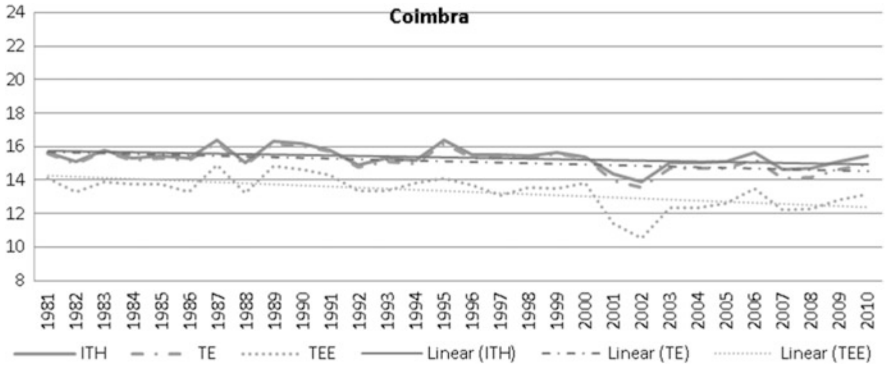

Fig. 4.8 Temporal evolution and linear trend of average annual values of THI, ET and EET at 06 UTC in Coimbra during the summer period (1981–2010)

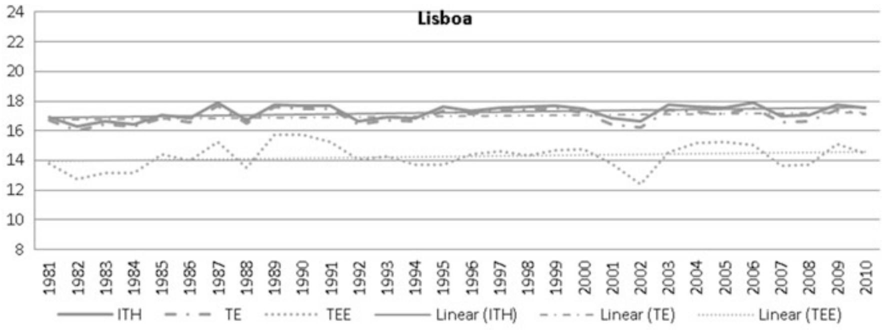

Fig. 4.9 Temporal evolution and linear trend of average annual values of THI, ET e EET at 06 UTC in Lisbon during the summer period (1981–2010)

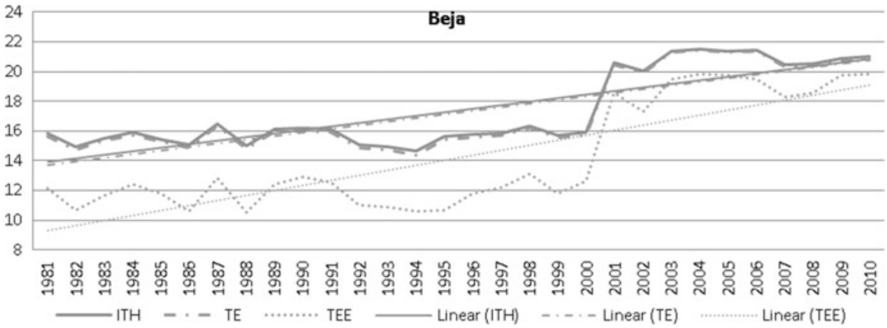

Fig. 4.10 Time evolution and linear trend of average annual values of THI, ET e EET at 06 UTC in Beja during the summer period (1981–2010)

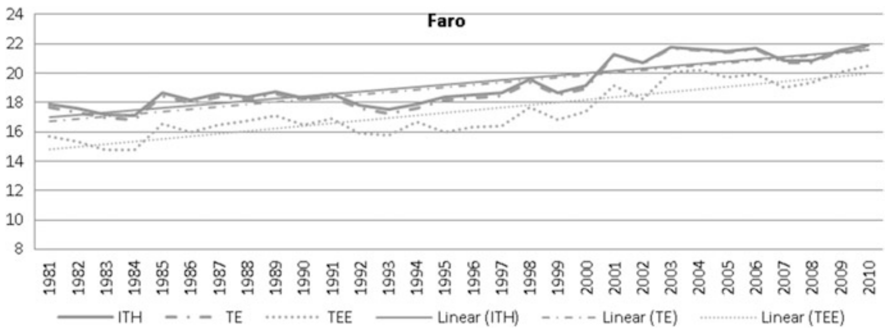

Fig. 4.11 Time evolution and linear trend of average annual values of THI, ET and EET at 06 UTC in Faro during the summer period (1981–2010)

boosting the nuclei of heat islands occurring during the day and which are strongly attenuated overnight due to the accumulation of cold air originating in the Katabatic

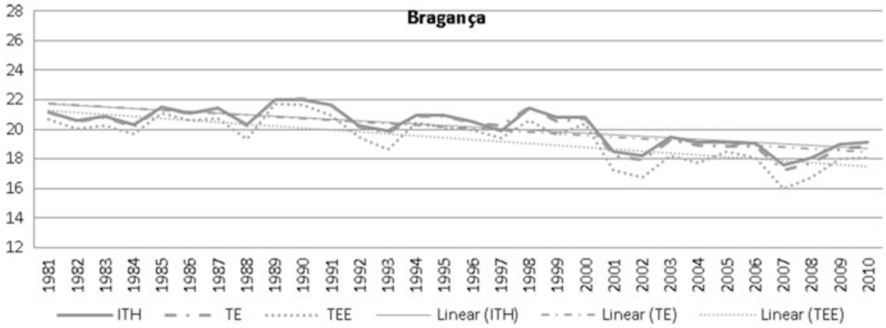

Fig. 4.12 Time evolution and linear trend of average annual values of THI, ET and EET at 18 UTC in Bragança during the summer period (1981–2010)

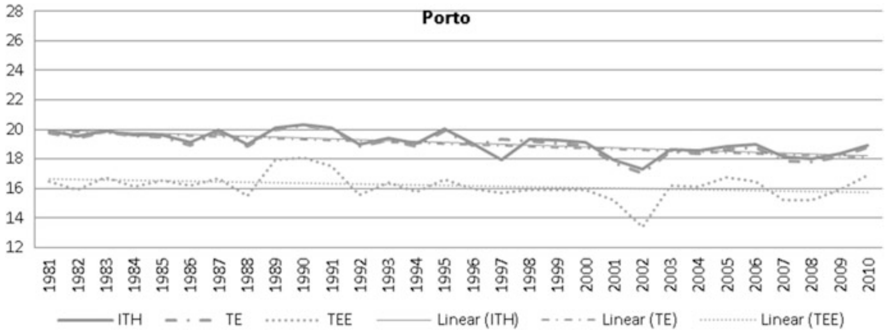

Fig. 4.13 Time evolution and linear trend of average annual values of THI, ET and EET at 18 UTC in Porto during the summer period (1981–2010)

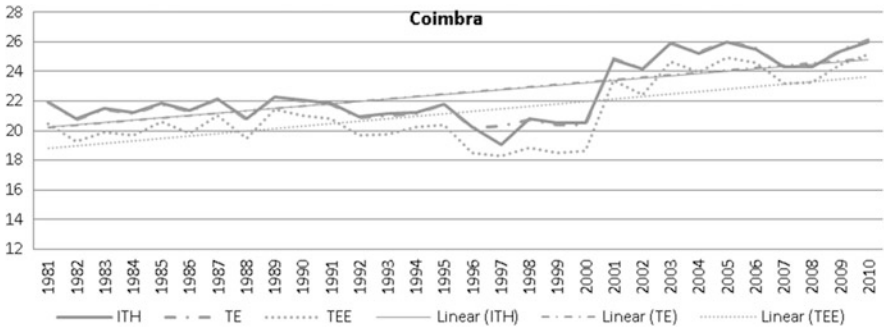

Fig. 4.14 Time evolution and linear trend of average annual values of THI, ET and EET at 18 UTC in Coimbra during the summer period (1981–2010)

(Ganho 2009). Given the proximity of the ocean and the river (Mondego), night breezes improve thermal comfort during the early hours of the day.

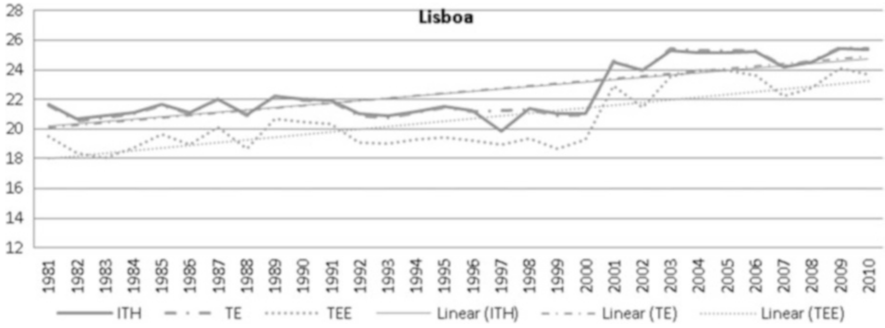

Fig. 4.15 Time evolution and linear trend of average annual values of THI, ET and EET at 18 UTC in Lisbon during the summer period (1981–2010)

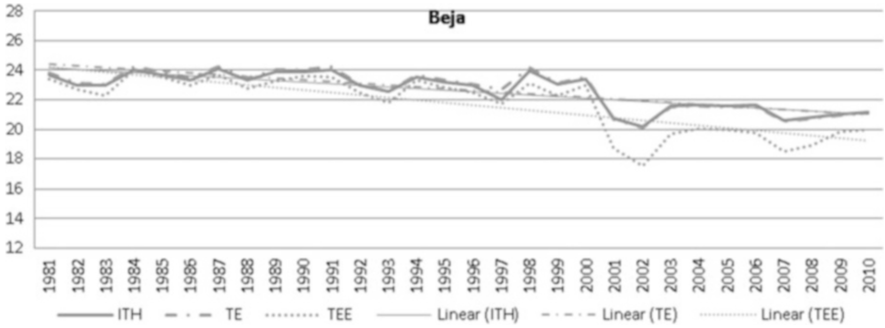

Fig. 4.16 Time evolution and linear trend of average annual values of THI, ET and EET at 18 UTC in Beja during the summer period (1981–2010)

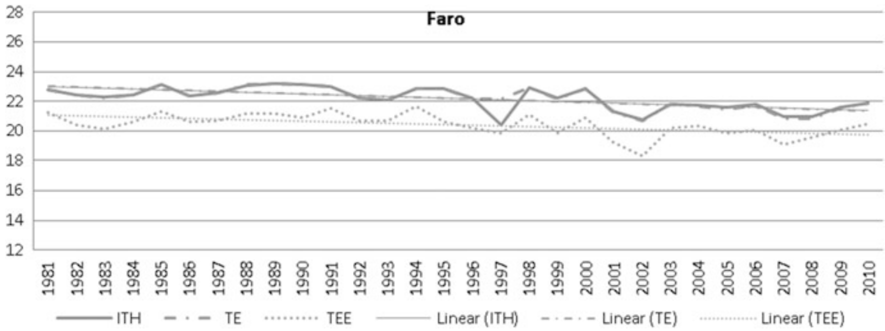

Fig. 4.17 Time evolution and linear trend of average annual values of THI, ET and EET at 18 UTC in Faro during the summer period (1981–2010)

The strong correlation between the variation of temperature and thermal comfort, as proved in section Spatial and Temporal Framework of this chapter, should also be noted.

At 18 UTC (Figs. 4.12, 4.13, 4.14, 4.15, 4.16, and 4.17), Coimbra and Lisbon boast slight increase in the values of bioclimatic indexes, particularly from the year 2000. There may be several causes for this phenomenon, particularly the higher average temperatures recorded in recent years. At the remaining stations, the linear trend lines are relatively constant, with the exception of Bragança and Beja, which may be indicative of the peri-urban character of these stations.

For Coimbra and Lisbon, their own internal urban microclimate dynamics, associated, for example, with the intensification of the urban heat island, can explain the abovementioned increase of bioclimatic indexes.

The analysis performed at this point shows that the evolution of the average annual values of bioclimatic indexes varies at the different weather stations, with many fluctuations over the period-sample. The results obtained for the THI index at 18 UTC, regarding the intensity of sensations, show significant contrasts between the different weather stations.

According to the intensity values obtained for situations of discomfort, Porto is the most comfortable, while Beja and Faro, the stations located at the lowest latitude, have a greater number of uncomfortable days and where, according to the intensity classes, more than 50 % of the population frequently feels discomfort. In Coimbra and Lisbon, there are even situations that generate strong bioclimatic stress and, consequently, medical emergencies (Fig. 4.18).

Results show that there are potential risks arising from this situation in Lisbon and Coimbra. Consequently, it is necessary to undertake studies that considered the importance of micro-climatic characteristics in these territorial units and their changing metabolism, units that this study does not consider because it was undertaken on a regional scale.

The distribution of mean values of EET in each of the sample years adheres to variation of the average of the previous two indexes but with lower values.

Heat Waves in the 1981–2010 Period

Identification of Heat Waves

Through the data obtained by applying the HWDI formula, it was observed that the total number of heat waves occurring at each weather station is distributed unevenly in temporal and spatial terms (Fig. 4.19). With regard to spatial variation, the Bragança weather station recorded the most waves during the period-sample (26), followed by the weather stations of Beja, Coimbra, Lisbon, Porto and, finally, Faro.

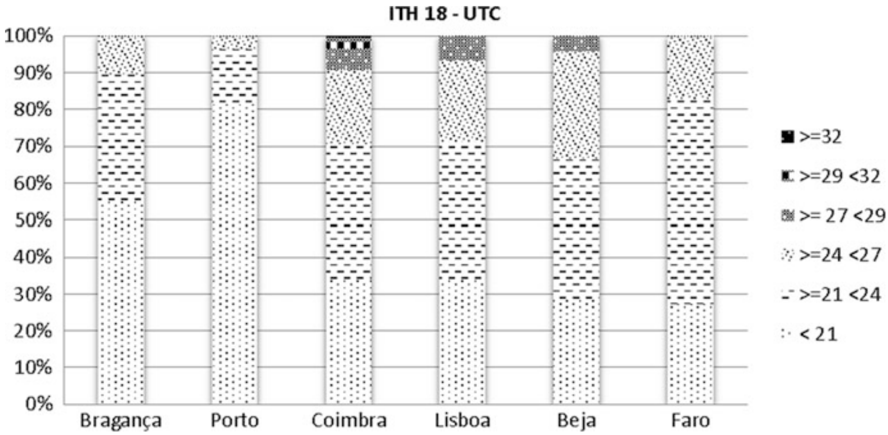

Fig. 4.18 Distribution of classes of THI at 18 UTC in Bragança, Porto, Coimbra, Lisbon, Beja and Faro during the summer period (1981–2010)

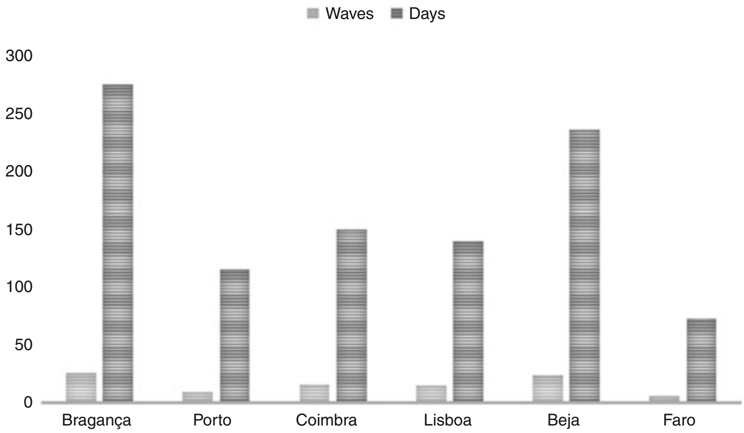

Fig. 4.19 Total number of heat waves and associated days in the study period

The Atmospheric Circulation Associated with the Occurrence of Heat Waves

This analysis used surface synoptic charts (level pressure on sea water and wind to 10 m) and 500 hPa at altitude (geopotential and wind at 500 hPa). For each selected situation, the day before and after the heat wave was considered, in order to contextualize the synoptic situation.

The terminology used in this study was proposed by Ramos (1987) and used by several authors. For all studied episodes, a synoptic classification of surface and altitude was made. To catalogue synoptic situations in surface and altitude, the criteria and classification codes proposed by Ganho (2000) were employed.

For the classification of surface synoptic situations, the distinction between anticyclone situations and synoptic disturbances was made, and, in relation to the latter, between frontal disturbances and depression centers related to cold pool situations.

With respect to situations at altitude, zonal circulation schemes, wave circulation and blocking circulation that reached the Western and Eastern Atlantic sector were considered.

Examining all heat waves days recorded from 1981 to 2010, we see that surface circulation corresponds to anticyclones, 95.5 % of the time, while the remaining days (4.5 %) indicate situations related to thermal origin depressions.

In relation to the typology of anticyclones (Fig. 4.20) causing heat waves, we can see the predominance of mixed Atlantic anticyclone (60 % of days). This type of anticyclone is also the most frequent in the summer, providing a westerly or northwesterly flow that mainly affects the coastal area. Mixed Atlantic anticyclones extending to Western Europe were also very significant in relation to the occurrence of heat waves (24 %).

Despite being less frequent, the Iberian-Mediterranean and Iberian-African anticyclones (Fig. 4.20) should be highlighted, due the extent of thermal discomfort they caused.

At altitude, during the occurrence of heat waves, meridian circulation clearly prevailed (Fig. 4.21), accounting for 65.8 % of the days (38.4 % in wave regime and 27.4 % in blocking scheme).

Zonal circulation occurred on the other 34.2 % of heat wave days. In the case of zonal circulation, disturbed circulation occurred in most situations (20 %). The remaining situations occurred under anti-cyclonic conditions (14.2 %), which is characteristic of this time of year.

Despite the predominance of zonal circulation during the summer period, the most intense heat waves occurred in meridian situations that were associated with wide-range anticyclone ridges, which extend from North Africa to southern Europe.

Given the above, it is concluded that the study of atmospheric generators of heat-related extreme event systems is both very important and urgent, due to climate change scenarios and associated consequences. Research combining several fields of knowledge and spheres of action can contribute to more effective risk anticipation or risk communication.

Conclusions

Situations of thermal discomfort are a common feature of the summer season in Portugal. Studying six weather stations located in climatically distinct areas allowed the observation of spatial contrasts, as well as the factors explaining them.

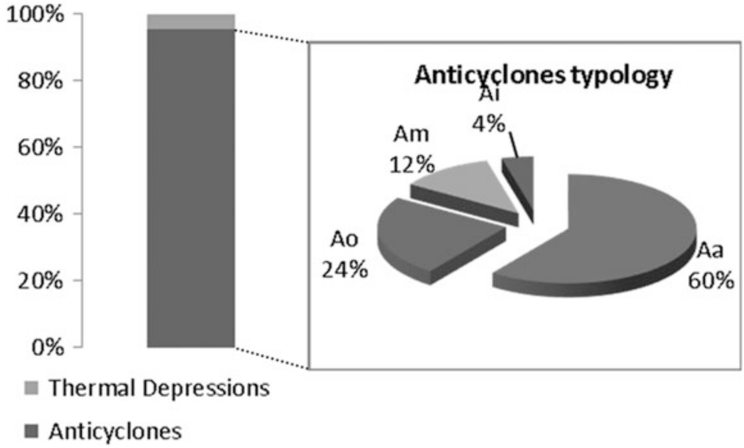

Fig. 4.20 Synoptic situations surface (n, m, m). Legend: *Aa* mixed Atlantic anticyclone, *Ao* mixed Atlantic anticyclone extending to Western Europe, *Ai* anticyclone Iberian-African, *Am* anticyclone Mediterranean

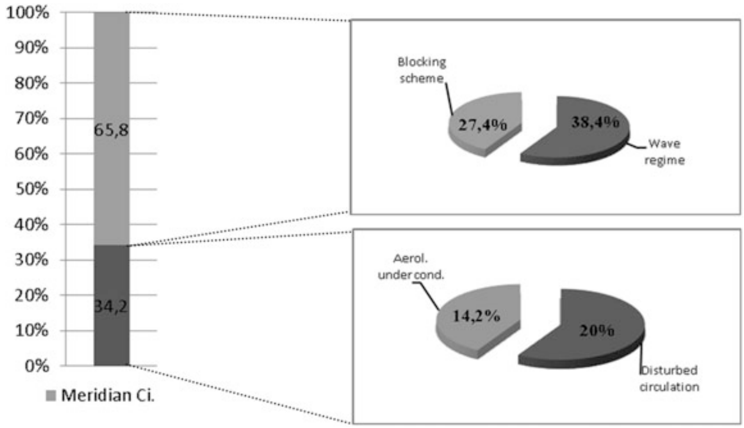

Fig. 4.21 Frequency of different types of anticyclone and situations at altitude (500 hPa) during heat waves (1981/2010)

Situations of discomfort in summer (1981–2010) are, primarily, the result of high temperatures, but also influenced by relatively high humidity (particularly at 06 UTC) at most of the weather stations studied. The combination of high levels of these two elements was the main cause of thermal discomfort. The role of wind speed as a moderator of thermal discomfort recorded by EET index is felt most at 06 UTC, slightly mitigating the intensity of the discomfort caused by heat.

In bioclimatic terms, the months of June and September are less uncomfortable at 06 and 18 UTC, while July and August, which boast higher average temperatures and a slight drop in relative humidity, are the most uncomfortable. However, the temporal distribution of greater bioclimatic discomfort (frequency and intensity) is quite irregular.

The number of heat waves occurring at each of the weather stations was considered relatively high, with the exception of Faro. In the case of Bragança and Beja, the high frequency of heat waves can be explained by the continental character of the regions where they are located.

Synoptic causes of these episodes are due almost exclusively to the Atlantic (Azores) anticyclone position, which, with the migration of the polar jet to the north during the summer, allows this high pressure cell to increase its latitude and reach mainland Portugal with greater frequency and intensity.

It is therefore vital to take relevant and efficient action in order to mitigate risks, reduce their effects and make the population aware of the need to adapt to such paroxysms. To this end, knowledge of specific risks, the identification of elements at risk and the assessment and quantification of vulnerabilities are essential for effectively planning prevention and protection, thus improving people's quality of life in bioclimatic terms.

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Susana Margarida Oliveira Moço Master Science Degree in Physical Geography (2005) from Universidade de Coimbra, Portugal; PhD in Geography (2015) in Universidade Aberta, Portugal is currently a collaborator of the CESAM (Environmental Studies Center and the Sea), University of Aveiro, were, she also is Researcher. Her main research and teaching areas include environmental sciences, environmental impact assessment, sustainability, environmental ethics and environmental citizenship and participation, and e-learning in science education and design pedagogical support tools.

José Eduardo Ventura Master Science Degree in Physical and Regional Geography (1986) from Universidade de Lisboa, Portugal; PhD (1995) and Aggregation (2010) in Environment and Natural Resources from Universidade Nova de Lisboa, Portugal. Assistant Professor with Aggregation in the Department of Geography and Regional Planning (Faculdade de Ciências Sociais e Humanas/Universidade Nova de Lisboa). His main research and teaching areas include Climatology, Environment and Global Change, Land Use Changes and Extreme Climatic Events. He is Senior Researcher at the Centre CICS.Nova of Faculdade de Ciências Sociais e Humanas/ Universidade Nova de Lisboa. He is coordinator of speciality area of Environment and Natural Resources in the Master Degree of Territorial Management at the Department of Geography and Regional Planning (Faculdade de Ciências Sociais e Humanas/Universidade Nova de Lisboa).

Manuela Malheiro Ferreira, PhD, MA, BA. PhD in Geographical Education from the Institute of Education of the University of London, Doctorat of Troisième Cycle and DEA in Geographical Education from the University Denis Diderot Paris VII, DEA in Urban Geography from the University of Panthéon-Sorbonne Paris I and BA (Hons) in Geography from the Faculty of Arts of the University of Lisbon. She taught courses within undergraduate, master's and PhD degrees in Education and Geography. It has also directed numerous dissertations and doctorates in those fields. She has developed research in Geographical Education, Intercultural Education, Urban Geography, Education for Sustainability and Research Methodology in Human and Social Sciences. She was the Coordinator of international and national research projects in those fields. She published books, chapters of books and papers. She is the Scientific Coordinator of the Intercultural Communication Research Group of the Centre on Migrations and Intercultural Relations of Universidade Aberta, Lisboa, Portugal.