

## Summer sea breeze influence on human comfort in Funchal (Madeira Island) - Application to urban climate and tourism planning

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### Abstract

The influence of sea breeze on human comfort in Funchal (Madeira Island) is presented in this study. Two groups of days (with sea breezes and hot days) from June to September 2006 were analysed. The Physiologically Equivalent Temperature (PET) was used to evaluate thermal comfort. It was concluded that most of the sites in the city are slightly comfortable during breeze days. When hot days occurs only shore line and the higher green places can be comfortable. It is advisable that during hot periods more vulnerable tourists visit higher altitude places, gardens and acclimatized buildings in order to prevent thermal stress situations. Urban planners should not promote dense construction near the shoreline that prevents the renovation of the air inside the city.

### 1. Introduction

Thermal comfort is the psychological state of mind that expresses satisfaction of people with the thermal surroundings and is usually referred to in terms of whether someone is feeling too hot or too cold (Mayer 2008). Human thermal complex is therefore balanced by thermal surroundings and metabolic processes.

Madeira (32°38' N and 16°55' W) is a mountainous Atlantic island (Pico do Areeiro: 1816 m and Pico Ruivo: 1862 m), 660 km away from the North Africa coast and 980 km from Lisbon. A great part of its population (245 000 inhabitants in 2001 census) is concentrated in the city of Funchal (41%), located in the southern slope (fig.1).

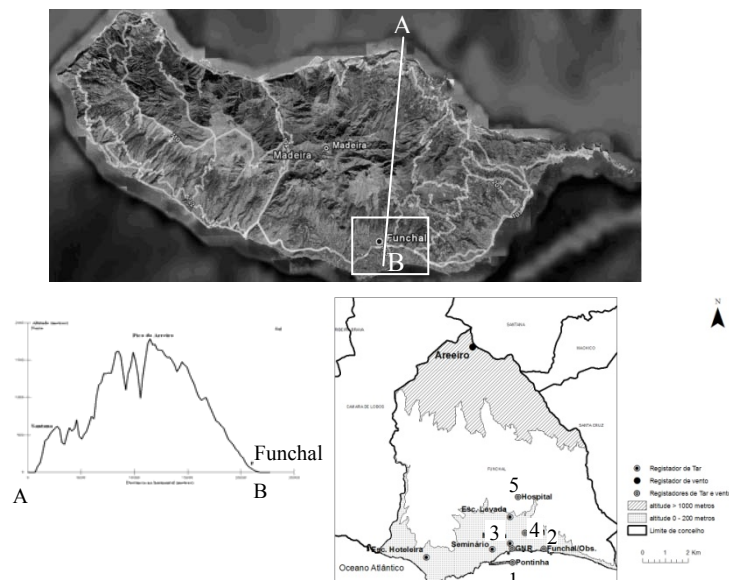


Fig. 1: Madeira Island and Funchal region. Meteorological observation sites: 1-Pontinha; 2-Funchal/Obs.; 3-Police station; 4-Firemen station; 5-Hospital. Sources: Image©2010 SRES DRIGOT; ©2010 Tele Atlas; Data SIO, NOAA, U.S. Navy NGA, GEBCO; ©2010Google and Lopes (2007)

The location in the Atlantic, the mountains, the *laurissilva* forest, and the compact city of Funchal originates a great variety of local climates.

The local economy is centred in the tourism activity of the two islands (Madeira and Porto Santo). According to the Statistics Bureau of Madeira the archipelago receives more than one million tourists per year (that corresponds to a revenue of 297 Million Euro). Recently the region was distinguished as an excellent travel destination by the CED (World Centre of Excellence for Destinations). Despite its importance, little attention is given to one of the attractiveness potential factors of the islands: its climate. For example, the most important climate information in the official site of Madeira Tourism is seasonal air and sea temperatures and only a “climate chart” (with monthly averages temperatures, total sunshine hours and precipitation) was found. This information is insufficient because present market rules impose accurate reporting to the consumers. In a previous study, Alcoforado et al. (1999) concluded that the climate information that was given to the tourists was fuzzy, incomplete or inaccurate, although climate is referred to by operators as an attraction factor for tourism. Climate information is often directed to specific high latitudes groups from North America or Europe, associating paradise tropical landscapes and climate/weather. Based on a methodology of weather types (with thresholds based on the sunshine hours, rainfall, maximum air temperature, vapour pressure and wind speed, measured at noon), the authors concluded that weather types were favourable for tourism and outdoor leisure activities even in wintertime where 50% of the days of December and January were considered “favourable for tourism and outdoor leisure activities” (Andrade et al, 2007).

## 2. Sea breeze in Funchal

Sea breezes are an important wind system to ameliorate urban environment and thermal comfort conditions. In Lisbon it was found that even if the breezes do not travel very far inland, they play an important role in cooling the urban air near the river bank, where air temperature may be up to 4°C lower than in the city centre (Alcoforado et al., 2009). In Funchal several types of sea breezes, defined by their characteristics (predominant wind direction and speed, duration, existing of veering dynamics or intermittence) were identified by Lopes (2007). During the period studied (May to September 2006), sea breezes occurred in 84% of the days, showing the persistence and the importance of this local wind system in the southern part of Madeira. The principal characteristics of the breezes are shown in table 1. They usually start in the morning (after 9:30 am) and end at night (after 10:00 pm), with an average total duration of about 11 hours and a mean velocity of 3 m/s.

Table 1: Characteristics of the sea breeze in Funchal (Pontinha), from May to September 2006. Source: Lopes, 2007

Type	Dominant direction	Beginning	End	Duration in hours (Avg.)	Mean wind speed (m/s)
		Median			
Regular	SW	9:20	22:40	10:35	4.0
	SW interrupted	9:25	22:40	10:35	3.2
	S and SE	10:00	21:25	12:20	1.9
Irregular	Other with veering	9:30	22:20	11:10	3.0
General Characteristics		≈9:30	≈22:20	≈11:00	2.9

On the top of the mountain (Pico do Arieiro) the wind blows prevailingly from the NE with a mean speed of about 6.7 m/s. The central mountain of Madeira acts as a barrier to the synoptic wind and on the southern slope the wind is highly modified by the relief. Therefore, due to its persistence, sea breeze is an important factor to ameliorate the human comfort in Funchal.

### 3. Methods and data

In the present research two groups of days from June to September 2006 were analysed: the first group corresponds to days where sea breeze occurred (total of 10 days from June to August); in the second group the temperatures were much higher than the averages for the period (3 to 6 September) and sea breezes hardly ever occur. For both groups wind speed and direction, air temperature, relative humidity and global radiation at 12:00 h and 18:00 local time were observed. Rayman software was used to calculate among other parameters the Physiologic Equivalent Temperature (PET) (Matzarakis et al., 2007). PET is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed (Höppe, 1999). The observation network (table 2) is operated by the LREC (Regional Engineering Laboratory) and the Portuguese Institute of Meteorology (IM).

Table 2: Urban characteristics of the observations sites (see locations in fig.1)

Site	Altitude (m)	Urban/topographic characteristics
Pontinha	5	Sea shore (marina)
Police station (GNR)	10	Urban near the shore line
Firemen brigade station (BVM)	50.	Urban (bottom of valley)
Funchal/Observatory (IM).	58	Suburban medium density.
Hospital	380	High city; suburban surrounded by vegetation.

The characteristics of the groups were chosen to give theoretical differences between places and to analyse the importance of the wind breeze in human comfort.

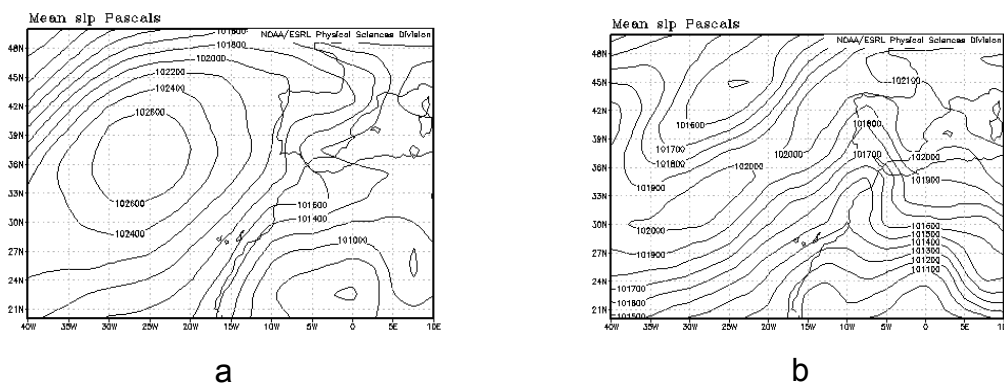


Fig. 2: NCEP/NCAR reanalysis of the 1st of August (a), representing breeze days and 3rd of September 2006 (b), showing the “African” eastern flux

During the period from the 3<sup>rd</sup> to 6<sup>th</sup> September 2006 the eastern flux from North Africa was regular and the wind blew with an average speed of 2.5 to 3 m/s (respectively at 12:00h and 18:00 h). This wind was replaced at the end of the afternoon by a land breeze, maintaining high air temperatures during the night (mean temperatures between 26°C at 12:00h and 27°C at 18:00h). Relative humidity was very high, with values about 90% near the shore and above 50% at the other observation points. Although the concept of heat wave can be discussed, according to WMO (WCDMP.No.47, WMO.TD No. 1071), a heat wave occurs when a period of six consecutive days have temperatures 5°C superior to average in the reference normal. The average temperature in September in Funchal is 23°C. Within the hot period presented in this study all the observation sites (except near the shore) registered temperatures around 30°C. When the sea breeze occurs, the eastern flank of the Azores anticyclone rules this part of the Atlantic. The northeast wind is dominant, but in the Funchal region it can be replaced by a breeze from the south and south west directions.

#### 4. Results and discussion

As can be seen in fig. 3 the hot days that occurred with the eastern flux from Africa are clearly uncomfortable especially at noon inside the city of Funchal. The better situation is near the shore line (Pontinha) where the wind speed is blowing more intensively (2.5 to 3 m/s) than the inner city (1.3 to 1.7 m/s). In the afternoon of the period from 2 to 6 September (hot days) a reduction of the uncomfortable situations (from hot to warm) can be explained by the reduction of global radiation (870 w/m<sup>2</sup> at noon to 240 w/m<sup>2</sup> at 18:00 pm) and a consequent decrease of 17°C of the Mean Radiant Temperature  $T_{mrt}$ .

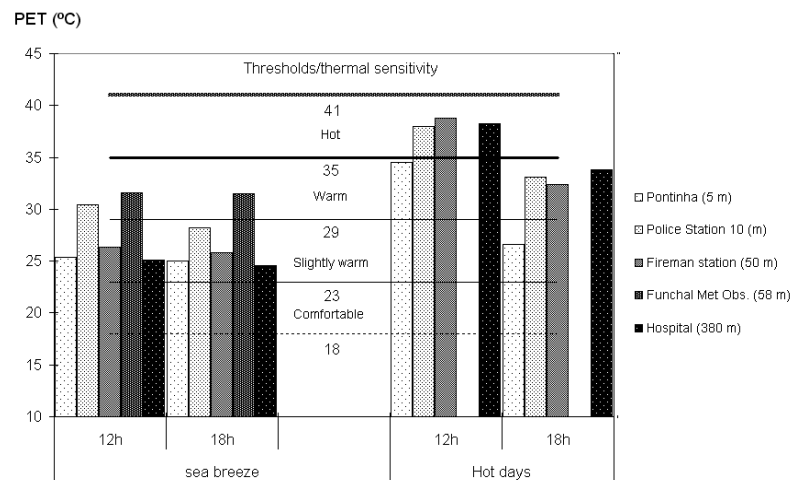


Fig. 3: Estimated PET for the two groups of days. Thermal sensitivity “Slightly warm” class corresponds to a grade of physiological stress of “Slight heat stress”; “Warm” to “Moderate heat stress”; and “Hot” to “Strong heat stress” (according to Matzarakis, 2006)

In both cases near the shore line (Pontinha) is always comfortable, more than the other places. During the breeze days, individuals can have better levels of thermal comfort only in the suburban elevated places of Funchal (such as near the Hospital, located at 380m, and surrounded by green spaces). Even near the ocean, but surrounded by dense construction (Police Station site), the environment may be warmer and stressful.

The hourly data presented in fig. 4 (PET, wind speed and south sea breeze direction and air temperatures) during the hot period reveal the role of the urban structure in the impoverishment of human comfort condition and the importance of sea breeze in the amelioration near the coast line. The better comfort conditions of higher places in the Funchal suburban green areas (near the Hospital observation site) are obvious; there PET values are in average 7°C lower than inside the urban compact structure (Firemen and Police Station). Due to the proximity of the ocean the shore line is another comfortable location during hot periods, especially when south breeze attains inland. However this system does not produce effects inside the urban dense areas. This can be seen in the differences between the Firemen and Police Station observation sites and Pontinha (the last 4 to 5°C lower in average) with a maximum difference of 16 to 19°C during the day.

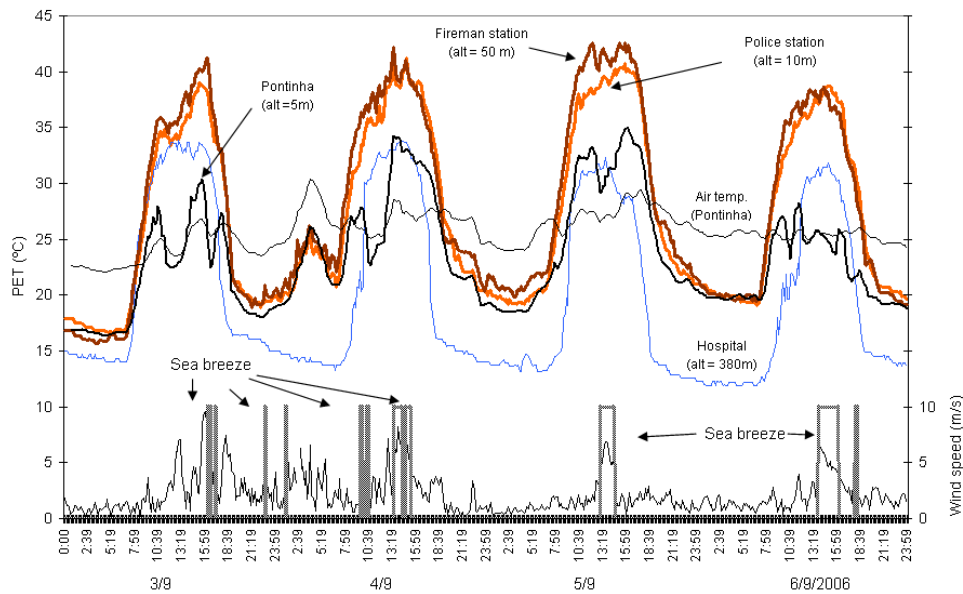


Fig. 4: PET within the warm period from 3 to 6 September 2006. Vertical bars (in the bottom of the graphic) correspond to southern sea breeze

## 5. Conclusions

Most of the tourists that choose the Madeira Island as a travel destination are people aged between 40 and 70 years old from north European countries (50% from UK and Germany). Therefore, tourism planning should attend to the thermal comfort issues and perception of such travellers. During the analyzed periods no absolute comfort situation was observed, although most of the sites in the city are slightly comfortable during breeze days. During heat waves like the one that occurred in September 2006, it is desirable that tourism agents can programme solutions to ameliorate the thermal comfort, especially northern Europe seniors who are not well acclimatized to hotter environments. As a response to escape too high temperatures, it is advisable to plan short trips to higher altitude superior to 400 m (outside the city of Funchal) or in controlled environments (visit to gardens and acclimatized buildings) during hot periods. Local authorities can also advise more exposed people to heat to remain near the shore line during the hours of higher air temperatures. As sea breezes are an important system to con-

trol heat stress urban planners should not promote dense construction near the shoreline that can act as a barrier to the renewable of the air inside the city.

### Acknowledgement

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