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CLIMATE AND PERCEPTION

An initial assessment of the bioclimatic comfort in an outdoor public space in Lisbon

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Abstract This paper describes the application of a methodology designed to analyse the relationship between climatic conditions and the perception of bioclimatic comfort. The experiment consisted of conducting simultaneous questionnaire surveys and weather measurements during 2 sunny spring days in an open urban area in Lisbon. The results showed that under outdoor conditions, thermal comfort can be maintained with temperatures well above the standard values defined for indoor conditions. There seems to be a spontaneous adaptation in terms of clothing whenever the physiological equivalent temperature threshold of 31°C is surpassed. The perception of air temperature is difficult to separate from the perception of the thermal environment and is modified by other parameters, particularly wind. The perception of solar radiation is related to the intensity of fluxes from various directions (i.e. falling upon both vertical and horizontal surfaces), weighted by the coefficients of incidence upon the human body. Wind was found to be the most intensely perceived variable, usually negatively. Wind perception depends largely on the extreme values of wind speed and wind variability. Women showed a stronger negative reaction to high wind speed than men. The experiment proved that this methodology is well-suited to achieving the proposed objectives and that it may be applied in other areas and in other seasons.

Keywords Outdoor bioclimatic comfort · Open urban area · Questionnaire survey · Physiological equivalent temperature · Thermal perception

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Introduction

Outdoor public spaces contribute to the quality of life in cities. They play an important role in the outdoor activities of urban dwellers (Thorsson et al. 2004) and contribute to strengthening social interactions between citizens (Nikolopoulou and Steemers 2003). Outdoor public spaces are areas accessible to the general public, such as streets, plazas, squares or parks, where people perform recreational and outdoor activities. These areas can exhibit great differences with regard both to the level of usage and to the types of activity performed (Cervera 1999; Zacharias et al. 2001). Recent research has shown that microclimatic conditions have a big effect on the usage of open spaces, partly because of their influence on levels of thermal and mechanical comfort (Nikolopoulou et al. 2001; Givoni et al. 2003). Thermal comfort is defined by ASHRAE (1966) as "the condition of mind in which satisfaction is expressed with the thermal environment". Mechanical comfort concerns the direct influence of the wind force upon people and objects, ranging from "the feeling of a light breeze on the skin to being blown over by a strong gale" (ACSE 2004; Blocken and Carmeliet 2004). However, the thermal and mechanical effects of wind are difficult to disentangle; bioclimatic comfort depends on a combination of both thermal and mechanical aspects. Obviously, the usage of space depends not only on climatic conditions but also on aesthetic and psychological aspects, among others (de Freitas 2003; Nikolopoulou et al. 2001; Zacharias et al. 2004).

Research on outdoor comfort has focussed mainly on thermal aspects, with the application of models developed for standard conditions, such as thermal comfort indices: e.g. the physiological equivalent temperature (PET: Höppe 1999; Matzarakis et al. 1999), the predicted mean vote (PMV: Fanger 1972; Jendritzky and Nübler 1981; Parsons 1993) and the standard effective temperature (SET: Parsons 1993; Chen et al. 2004), derived mostly from studies of indoor comfort and experiments carried out in wind tunnels (Zacharias et al. 2001; Svenson and Eliasson 2002). Nevertheless, the steady-state conditions assumed in these models are not adequate to the study of the highly variable conditions encountered outdoors (Parsons 1993; VDI 1998; Nikolopoulou and Steemers 2003; Thorsson et al. 2004). A purely quantitative approach is insufficient to understand the complexity of the outdoor environment and it has been recognised that subjective parameters must be included in the analysis of outdoor human comfort (Höppe 2002; Ahmed 2003; Nikolopoulou and Steemers 2003; Stathopoulos et al. 2004; Knes and Thorsson 2006).

Outdoor climatic comfort, its perception and, consequently, the use of open spaces are influenced by the microclimatic conditions, particularly air temperature, air humidity, wind speed and radiation fluxes (especially solar radiation), by a set of personal parameters, such as physical activity, level of clothing and age, and also by psychological factors, namely motivation, individual preferences and cultural aspects (Nikolopoulou and Steemers 2003; Stathopoulos et al. 2004; Knes and Thorsson 2006). Understanding the relationship between environmental conditions (including the microclimate), human characteristics and the usage of open urban spaces can contribute to improving open outdoor spaces and to the design of more attractive new spaces.

The aim of the current study is to provide a comprehensive assessment of the relationships between the different parameters that influence outdoor human comfort in open urban areas. Research on this subject began only recently and few studies have been carried out to date; for this reason it was necessary to first define a framework methodology that could assist us throughout the development of this study and that would be suitable for application in different geographical and meteorological contexts. This has been achieved through a pilot study carried out in Lisbon in the late winter and spring of 2006.

This study is part of the research project “URBKLIM: Climate and Urban Sustainability. Perception of comfort and climatic risks” (POCI/GEO/61148/2004) and has the following objectives: (1) to assess the conditions of human comfort in different outdoor open spaces; (2) to define thresholds of climatic comfort in outdoor spaces based on the atmospheric conditions, type of activity and individual characteristics; and (3) to analyse the relationship between the perception of climatic comfort and microclimatic conditions in different urban areas. This paper presents and discusses the methodology applied in the pilot study, as well as its results.

Materials and methods

Study area

Lisbon is the capital of Portugal and its largest city (Fig. 1). It is located at 38°43′ latitude N and lies 30 km to the east of the Atlantic shore, on the bank of the Tagus estuary, in an area with a highly differentiated topography. The climate is Mediterranean, characterised by mild, wet winters and dry, hot summers, which partly explains why its population frequently engages in outdoor activities, especially during spring and summer. Studies of Lisbon’s urban climate have been undertaken since the 1980s at the Centre of Geographical Studies of the University of Lisbon and have focussed on the Urban Heat Island (e.g. Alcoforado 1992; Alcoforado and Andrade 2006), on the city’s bioclimatic conditions (e.g. Andrade 2003; Andrade and Alcoforado 2007), on the consequences of the city’s growth upon ventilation conditions (Lopes 2003), and on the application of climatic studies to urban planning (Alcoforado and Matzarakis 2007).

Lisbon has a wide range of outdoor public spaces, ranging from green areas to riverside walks, squares and parks, which have different environmental characteristics and microclimatic conditions. A riverside area in the southern part of the city was selected for the pilot study (Fig. 2). It stretches between the river Tagus to the south and a main road to the north and is approximately 15 m long. It comprises a paved sidewalk and green areas and is bordered by deciduous trees on both the east and west sides. There are benches facing south in both the green and paved areas. The area is used by the inhabitants of the city mainly for promenading, especially during the weekend.

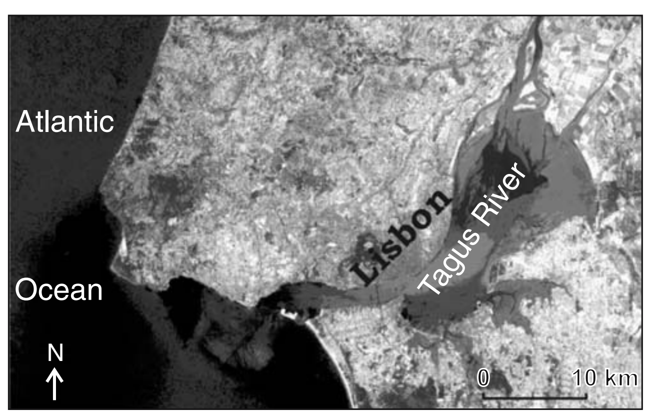

Fig. 1 The Lisbon region

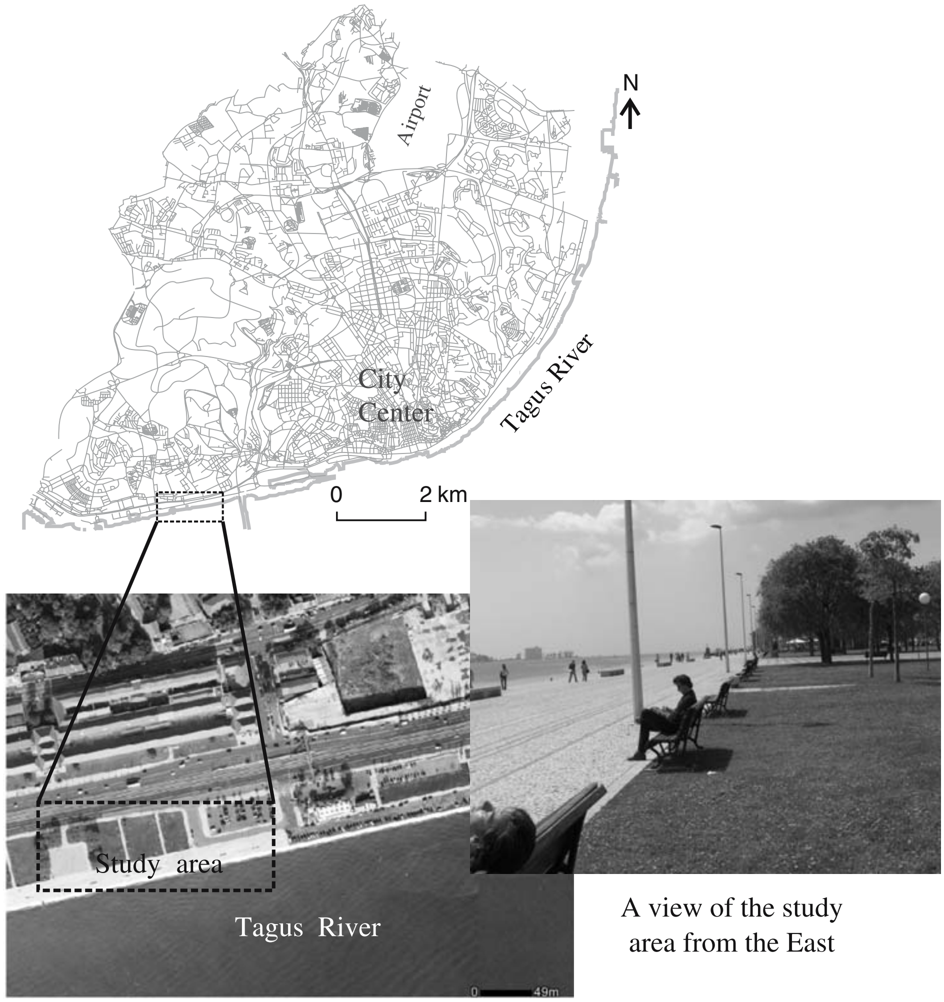

Fig. 2 The study area

Field data collection

The field data collection included questionnaire surveys and the measurement of weather parameters during sessions that lasted from approximately noon until 5 p.m. Photographs of the study area were also taken during those sessions, in order to monitor any behaviour by users of the area that might indicate adaptation to environmental and climatic conditions.

The field studies were conducted in late winter and spring, specifically on 12 March and 23 April—both warm, sunny Sundays. The sky was partly cloudy, temperatures were above the monthly average and the wind speed was variable, with an average of 1.9 m s^{-1} on 12 March and 2.6 m s^{-1} on 23 April but reaching a maximum value of 6.8 m s^{-1} (Table 1).

Weather measurements

The weather parameters measured in order to characterise the general weather conditions in the study area (local scale) and the thermal environment in which individuals move (micro scale) were air temperature (T_a), relative humidity (RH), wind speed (v) and solar (K) and long wave (L) radiation. With the purpose of assessing the changes in the thermal environment during the questionnaire session, a Tinytag 433–7841 thermo-hygrometer (Gemini Data-loggers, Chichester, UK) was placed on a lamppost at a height of 2 m in the green area, facing north and sheltered from solar radiation, which recorded T_a and RH every 10 min.

Microclimatic measurements were carried out near the interviewees while the questionnaires were taking place (Fig. 3). The values of T_a, RH and v were recorded every 30 s using Testo probes: T_a was measured with an NTC thermostat with an accuracy of 0.2°C, whereas v was measured using a thermal anemometer (warm bulb) with an accuracy of 0.3 m/s at 22°C and a time of response of 4 s. K and L were measured using a pyranometer CM21 Kipp & Zonnen and a pyrgeometer CG1 Kipp & Zonnen, respectively (Kipp & Zonen, Delft, The Netherlands). Measurement of radiation fluxes was carried out every 15 min, using the procedure for bioclimatic purposes described in

Table 1 Meteorological conditions during the days on which questionnaire surveys were performed. Air temperature, wind speed and direction, cloudiness and solar radiation were recorded

	Air temperature (°C)					
	Measured in the study area			Measured in the meteorological Station Lisboa/Geofisico		
	Lowest	Average	Highest	Maximum	Average	Difference to normal 1961–1990
12 March (12.30 p.m. to 4.50 p.m.)	16.6	18.1	18.8	22.1	13.7°C	+4.5
23 April (2.20 p.m. to 5.50 p.m.)	21.3	22.7	23.5	22.9	15.1°C	+3.8

	Dominant wind direction	Wind speed in the study area (m s^{-1})			Cloudiness	Solar radiation (W m^{-2})			
		15th percentile	Average	85th percentile		Min	Time	Max	Time
12 March	East	1.2	1.9	2.5	Variable - high clouds	258	4.27 p.m.	873	12.30 p.m.
23 April	Northwest	1.2	2.6	4.2	Scattered cumulus	272	5.45 p.m.	937	1.20 p.m.

Jendritzky and Nübler (1981) and VDI (1998): both the pyranometer and the pyrgeometer were placed on a portable rotating tripod and, in order to measure both solar and thermal infrared radiation, four readings were taken towards the cardinal directions of the horizon, by rotating the device around its vertical axis, and two additional readings were taken, one upwards and one downwards, by rotating the device around its horizontal axis. This measurement scheme makes it possible to compute the mean radiative temperature (T_{mrt}) using the method described in Jendritzky and Nübler (1981); T_{mrt} may be regarded as a synthesis of all the radiation fluxes.

Fig. 3 Equipment used to measure weather parameters. Foreground: *right* pyranometer, *left* pyrgeometer. Background: *right* Testo data logger with its temperature, relative humidity and wind speed measuring probes, with the Tinytag thermohygrometer with its shelter behind

The questionnaire

The questionnaire was applied to randomly selected people passing by on the sidewalk or sitting on the benches. In order to ensure that the sample was reasonably homogeneous, only young people and adults engaged in low or moderate physical activity were approached. The youngest interviewee was 17 years old.

The questionnaire was designed using concise and plain language in a short-answer format and could be completed in about 2 min. It was divided into two parts: the first part comprised the personal characteristics of the interviewees, while the second addressed the perception of comfort by the interviewees in relation to the weather parameters. The selection and structure of the questions were based on previous studies (Nikolopoulou and Steemers 2003; Stathopoulos et al. 2004; Knes and Thorsson 2006) that had demonstrated the importance of a person's individual characteristics and inherent psychological factors in the perception of comfort. The questionnaire is described in further detail in the following section.

Personal characteristics

Gender and age (Table 2, questions 1 and 8, respectively) influence the type of clothing worn and the level and type of activity performed. A set of psychological differences, depending mostly on age, can also be found to exist with regard to perception of environmental conditions. Moreover, both these characteristics affect the basal metabolic rate of heat production, which typically decreases with age (ISO 1990; Parsons 1993). Kalkstein (1997) reported that elderly people are in general more susceptible to heat, whereas Penwarden (1973) stated that high wind speeds may be more dangerous to elderly or infirm people than to fit and active ones. Previous studies have also shown that males and females have different thermal comfort responses (Parsons 2002) and that females are more sensitive to heat stress than males (e.g. Kysely 2004).

Clothing (Table 2, question 5) creates a barrier between the human body and the environment. In outdoor conditions, people wear different clothing in different seasons (Givoni et al. 2003) and the choice of clothing may also vary from person to person within the same season. In order to characterise the level of clothing, a simple scale was created, based on the three types of clothing ensembles that people most typically wear in Portugal at this time of year (late winter and spring), and which are considered appropriate for the prevailing climatic conditions (Fig. 4). The questionnaire also considered the possibility of adding other specific garments (Table 2, question 5—extra elements), in order to cope with the potential variety of clothing to be found during the field surveys. For example, Penwarden et al. (1978) have argued that it is possible to establish an association between the level of mechanical comfort perceived by individuals and the type of clothing worn and, in particular, have found (based on wind tunnel experiments) that women who wear skirts feel more disturbed by the wind than women who wear trousers.

Although quantification was not the foremost aim of this study, a general relationship was established between this scale and the values of thermal resistance of clothing

Table 2 The questionnaire (part 1)

1. Sex	
F	
M	

2. Exposure	
Sun	
Shade	

3. Company	
Alone	
Not alone	

4. Activity	
Rest	
Read/ Write	
Talk	
Walk slowly	
Walk fast	
Other:	

5. Clothing	
A	
B	
C	
Extra – elements	
Long coat	
Thick coat	
Thick sweater	
Boots	
Sleeveless coat	
Scarf	
Hat	
Gloves	
Skirt	
Short sleeves	
Shorts	
Other:	

6. Position		
Standing		
Sitting	Bench	
	Grass	
	Floor	
	Other	
Lying down	Bench	
	Grass	
	Floor	
	Other	

7. Other char.	
Pale skin	
Dark skin	
Fat	
Thin	

8. Age	

9. Place of birth

10. Residency

11. For how long

12. Professional activity

13. Do you smoke?	
Yes	
No	

14. For how long have you been in this place	
< 5 min	
5 to 15 min	
15 to 30 min	
30 min to 1 hour	
> 1 hour	

15. Where were you before coming here (last hour)	
Own car	
Public transport	
Inside a building	
At home	
On the street/outside	
Other:	

16. Reasons to be in this place			
Rest		Passage to another place	
Walking by		Taking care of children	
Recreational activity		Shopping	
Meeting friends		Other:	
Work (break time)			

17. How often do you come here?	
First time	
1 or 2 times per year/occasionally	
1 or 2 times per year	
1 or 2 times per week	
More than 2 times per week	

18.1. Do you have any of these diseases?			
Asthma		Rheumatism	
Bronchitis		Arthritis	
Rhinitis		Another bone-related disease	
Pulmonary obstructive disease		Eczema	
Another respiratory disease		Another skin problem	
Other Allergy		Cardiac/cardiovascular disease	
Diabetics		Other	

18.2. How do you feel now in relation to your health conditions?	
Very uncomfortable, symptoms aggravated	
Uncomfortable, disease manifestation	
Well, comfortable	
Very well, no symptoms	

18.3. What type of weather aggravates your health conditions?									
a. Temperature		b. Humidity		c. Solar radiation		d. Wind		e. Precipitation	
Cold/cool		Dry		Gloomy		No wind		No rain	
Warm/pleasant		Neutral		Pleasant		Pleasant		Raining	
Hot		Humid		Sun is a little strong		Windy		Heavy rain	
Very hot		Very humid		Sun is too strong		Very windy		Thunderstorm	

Questions concerning the personal characteristics of the interviewees

Fig. 4 Types of clothing ensembles

expressed in clo units (which measure the thermal insulation required to keep a sedentary person comfortable at 21°C), based on Parsons (1993; Table 3).

Both the type of exposure (in direct sun as opposed to in the shade; Table 2, question 2) and body position (standing, sitting or lying down; Table 2, question 6) affect the way each individual experiences the thermal environment, by giving rise to changes in the radiative input and in the area of exchange between the human body and the atmosphere. The subjects' posture greatly affects the heat exchange between the human body and the environment (Underwood and Ward 1966; Parsons 1993) and may also constitute a form of behavioural adaptation to climatic conditions.

In order to calculate the metabolic rate, which refers to the production of heat by the human body, it is necessary to determine the level of activity of the individual at the moment of the enquiry. Different levels of physical activity were thus considered (Table 2, question 4), based on the assumption that the interviewees were performing only low or moderate physical activity; the average value of metabolic heat production was estimated based on Auliciems (1997) and is shown in Table 4.

The places of birth and residence (Table 2, questions 9–11) play an important role in determining how individuals experience the climatic conditions in the study area, by influencing their expectations and their perception of comfort (Nikolopoulou and Steemers 2003). For example, in a study carried out in Italy, Vigotti et al. (2006) found that people born in warmer areas exhibit higher tolerance to heat. The individuals' professional occupation (Table 2, question 12) can also affect their experience of specific climatic conditions and thereby influence their degree of tolerance to different outdoor conditions.

The length of time spent in the area also influences the level of comfort (Table 2, question 14), because the human body requires a certain amount of time to adapt to environmental conditions (Ahmed 2003; Nikolopoulou and Steemers 2003; Thorsson et al. 2004). In a previous study carried out for the EXPO'92 in Seville, Spain, with the purpose of optimising the design of elements capable of modifying climatic conditions, Garcia et al. (1991) divided the open spaces of the Exposition Area into three

Table 3 Description of the different types of clothing ensembles and additional pieces of clothing considered and their respective clo values (based on Parsons 1993)

A	Clo	B- Standard	Clo	C	Clo
Underwear	0.03	Underwear	0.03	Underwear	0.03
Trousers	0.25	Trousers	0.25	Trousers	0.25
Shirt or blouse long sleeves	0.25	Shirt or blouse long sleeves	0.25	Shirt or blouse long sleeves	0.25
Shoes (w/ socks)	0.04	Sweater or coat	0.28	Sweater	0.28
		Shoes (w/socks)	0.04	Coat or jacket	0.6
				Shoes (w/socks)	0.04
Total	**0.57**	**Total**	**0.85**	**Total**	**1.45**

Extra – elements	Clo
Long coat	0.7
Thick coat	0.8
Thick sweater	0.35
Boots	0.1
Sleeveless vest	0.12
Scarf	0.08
Hat/cap	0.10
Gloves	0.05
Skirt	0.2
Short sleeves	0.15
Shorts	0.06
Other:	Variable

Table 4 Types of physical activity and average metabolic rate of individuals engaged in those activities (Auliciems 1997)

Activity	Metabolic rate (W m^{-2})
Resting (sitting)	60
Standing	90
Reading/ writing	100
Talking	100
Walking slowly	120
Walking fast	160
Other	Variable

categories: “strolling pathways” with a usage time of up to 15 min, “resting zones”, where people would stay for 20–40 min, and “adjacent zones”, an intermediate category. As a result, different comfort targets were defined for each of these categories, demonstrating the importance of analysing the time spent in a given area when assessing levels of outdoor comfort.

Individuals’ expectations are also affected by their companions (Table 2, question 3) and by their short-term thermal history (Table 2, question 15) (Nikolopoulou and Steemers 2003). Question 7 (Table 2) addressed a small list of characteristics not covered by the other questions, particularly skin colour, which can influence the skin absorvity to *K* (Dirmhirn 1964, cited in Höppe 1992) and the fatness/thinness of an individual, which can influence thermoregulatory processes (Parsons 1993). These characteristics were recorded only when they were present in an accentuated form (very dark or very light skin, very fat or very thin individual).

Psychological expectancy can derive from the reasons for using the space (Table 2, question 16), which can affect subjective assessments and satisfaction (Auliciems and De Dear 1997; Thorsson et al. 2004). Höppe (2002) stated that the expectation of specific thermal conditions is the main aspect determining personal satisfaction. The possibility of choice and the voluntary character of the exposure increase people’s tolerance to environmental conditions (Thorsson et al. 2004). Indeed, people are aware of the lack of control over outdoor conditions and thus they regard conditions as “satisfactory” over a wider range than indoors (Spagnolo and DeDear 2003), as the perceived choice over the source of discomfort becomes more important than the actual physical conditions (Nikolopoulou and Lykoudis 2006). Furthermore, the existence of a relationship between a person’s mood and the assessment of the environment has recently been acknowledged (Knes and Thorsson 2006). Experience (Table 2, question 17) directly affects people’s expectations and adaptation to the specific environment (Nikolopoulou and Steemers 2003) and thereby influences the subjective assessments they make.

The climate affects human health both directly and indirectly (McGregor 2001), and individuals who suffer from a specific health condition may be more vulnerable or sensitive to certain climatic conditions (Schlink et al. 2002). For this reason, the questionnaire included a list of selected diseases that may be related to atmospheric and climatic conditions (Table 2, question 18.1). Respiratory diseases are among such diseases (McGregor et al. 1999; Schlink et al. 2002); respiratory infections are more common under certain weather conditions, as illustrated by the increase in the number of general practitioner consultations (Nastos and Matzarakis 2006). Allergies are most frequent in the springtime, due to the dispersal of pollen, and under windy conditions, because the wind can scatter allergenic particles (Todo-Bom 2003). Other diseases were also considered: diabetic people are more vulnerable to low temperatures, because their metabolic rate decreases and the amount of sugar in the blood increases, which increases the need for insulin (Parsons 1993). Rheumatism and other bone-related diseases are usually associated with humidity and cold (Besancenot 2001), whereas cardiac and cardiovascular diseases increase vulnerability to extreme thermal conditions (McGregor 2001). The existence of a smoking habit was also recorded (Table 2, question 13) because it affects respiratory capacity. Question 18.3 (Table 2) was designed to ascertain the extent to which people know whether and how the weather affects their health condition, in an attempt to understand people’s awareness of this subject.

The perception of bioclimatic comfort

The second part of the questionnaire concerned the perception of each weather parameter experienced at the moment of the enquiry (T_a, HR, v, K) (Table 5, question 19), as well as the overall perception of the weather conditions by each individual (Table 5, question 21) using a 4-point nominal scale of comfort for simplicity purposes. The distinction between the perception of the overall conditions and that of the specific parameters was introduced because a general feeling of comfort (or discomfort) may not rule out the feeling that the climatic environment can still be improved by changing the weather parameters individually. These questions, although seemingly simple, involve complex problems, e.g. the importance of the psychological factors, which strongly interfere with the perception of comfort (Höppe 2002; Nikolopoulou and Steemers 2003). On the other hand, although it is technically quite straightforward to separate the thermal influence of the various weather parameters, the human body does not have the capacity to sense those influences separately, as shown in previous studies. Givoni et al. (2003) and Stathopoulos et al. (2004) stated that, in determining the level of overall comfort, certain weather

Table 5 The questionnaire (part 2)

19. At this moment, how do you feel the weather parameters in this area?							
a. Temperature		**b. Humidity**		**c. Solar radiation**		**d. Wind**	
Cold/cool		Dry		Gloomy		No wind	
Warm/pleasant		Neutral		Pleasant		Pleasant	
Hot		Humid		Sun is a little strong		Windy	
Very hot		Very humid		Sun is too strong		Very windy	

20. What is the most unpleasant weather parameter at this moment?	
a. Temperature	
b. Humidity	
c. Solar radiation	
d. Wind	
e. None	

21. How do you feel overall?	
Very uncomfortable	
Uncomfortable	
Comfortable	
Very Comfortable	

22. Do you think the climatic conditions would improve if:					
Parameters	Much lower	Lower	The same	Higher	Much higher
a. Temperature					
b. Humidity					
c. Solar radiation					
d. Wind					

Questions concerning the perception of the meteorological conditions and of the overall comfort

parameters depend upon others—for example, the assessment of air temperature depends on how solar radiation and wind force are perceived—and that, therefore, human beings have a limited ability to separately perceive the various meteorological elements.

Other questions sought to determine which weather parameter was perceived as most unpleasant by the respondents (Table 5, question 20) and how they would change the weather conditions in order to increase the level of comfort (Table 5, question 22). These questions were introduced because "perception" and "preference" have different meanings; the latter reflects the desire for ideal conditions, while the former reveals what people feel at the moment, compared to the normal conditions for that time of the year (Stathopoulos et al. 2004).

Data analysis

The answers to the questionnaire were analysed assuming the possibility of a relationship between three groups of parameters (Fig. 5): (1) the personal characteristics of the interviewees; (2) the perception of comfort revealed by the interviewees; (3) the atmospheric parameters measured during the interview. The main focus was the relationship between the recorded atmospheric conditions and the level of comfort stated by the individuals. In order to analyse this relationship, the ANOVA procedure was applied (Wilks 1995). The thermal influence, resulting from the combination of the various atmospheric parameters, was analysed using the PET (Mayer and Höppe 1987; Höppe 1999; Matzarakis et al. 1999), a thermo-physiological index based on the model of the energy balance of the human body, including all the relevant atmospheric variables and assuming constant levels of both clothing (0.9 clo) and metabolic heat production (H=80 W m^2). The assumption of constant values of clo and H makes it possible to isolate the analysis of the atmospheric environment from the influence of personal variables. PET values were computed using Rayman software (Matzarakis et al. 2007). The application of PET in the context of Lisbon's climate is discussed in detail in Andrade and Alcoforado (2007).

Results and discussion

91 interviews were carried out during the two field surveys, corresponding to about 10% of the total number of people

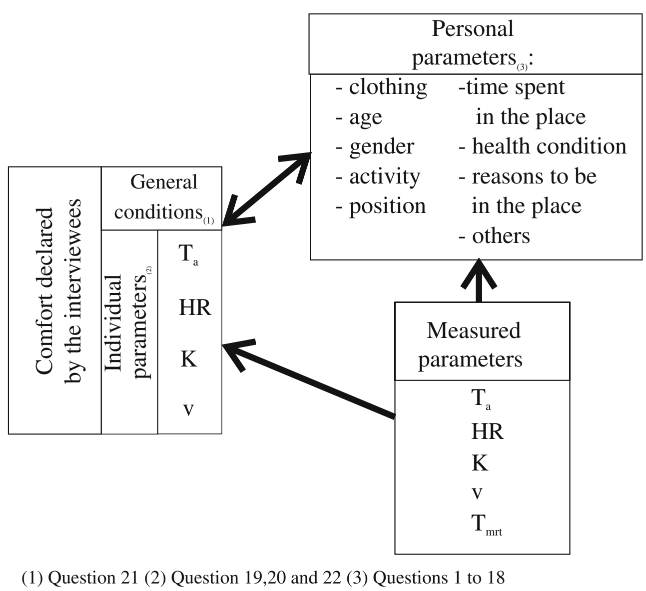

Fig. 5 Relationships between parameters influencing climatic comfort

using the study area on those days and during the time when surveys were being conducted.

About 55% of the individuals were women (Fig. 6). The age of the interviewees varied between 17 and 76 years of age and the predominant age group was 25–34 years (37%), followed by the 35–44 and 45–54 age-groups. Almost all the users of this open public space were residents in Lisbon or its surroundings; 47.3% were born in the Lisbon region and only 10% were nationals of other countries (mainly from Brazil and several African countries).

All the individuals were performing leisure activities in the area: 75% of the interviewees were in an upright position, almost all walking slowly, whereas 25% were seated on the benches; 34% had been in the area for less than 15 min and 26% had been there for more than 1 h at the time of the interview. All the individuals were in direct sunlight; during the two survey periods, the shaded areas were not used.

All the interviewees wore clothing characterised as being included in ensembles A or B (Table 3, Fig. 4), with a level of thermal insulation estimated at between 0.45 and 0.9 clo, with an average of 0.63 clo. There were no relevant differences regarding the most common types of clothing between the two sessions and, moreover, no noteworthy differences could be found in terms of clothing as a result of gender.

Perception of comfort and its relationship with clothing

Almost all the individuals claimed that they felt comfortable (Table 5, question 21), regardless of the broad range of T_a values recorded during the field work (between 18°C and 31°C); PET values also exhibited large variation (22.0°C–40.8°C), demonstrating the contrasts caused by exposure to wind and direct solar radiation.

In interpreting this result, both motivation (all the individuals were in the area for leisure purposes) and clothing must be taken into consideration. Although the relationship between the level of clothing worn and the thermal parameters is not linear, a clear differentiation with respect to clothing could be found between the people interviewed in the warmer periods and those interviewed at cooler times (with temperature assessed in terms of PET). The value of PET that seems to separate the two groups most accurately is 31°C. Below this limit, 56% of the individuals wore clothing ensemble B and 44% wore ensemble A; above this value, people wearing clothing ensemble A accounted for 84% of the total (Fig. 7).

The differentiation between these two classes of temperature (<31° and >31°C) was also confirmed by clo values (Table 6). The warmer class showed much lower values of all parameters and the standard deviation of clo values also decreased in this group. This result was tested using ANOVA and was found to be statistically significant (F= 9.43 for a significance limit of 3.95, with P<0.05). The relationship between the level of clothing worn and the air temperature was also analysed, but was not statistically significant.

The difference in clothing between these two groups of people, interviewed under different thermal conditions, can be regarded as an adaptation to the thermal conditions and partly explains the maintenance of the level of comfort even under different values of PET. These results are in accordance with the findings of previous studies:

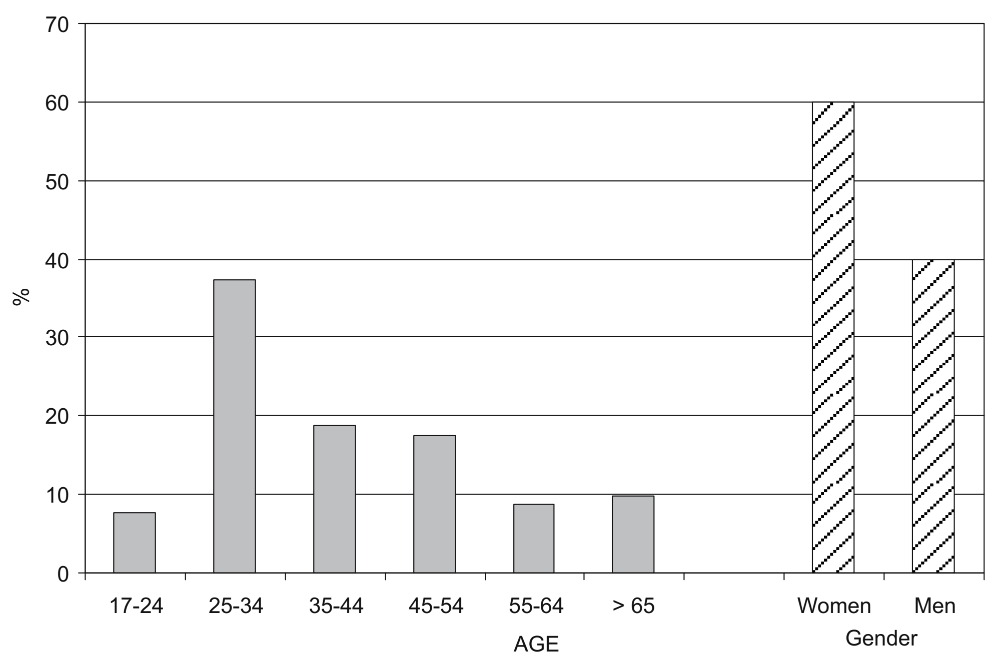

Fig. 6 Characterisation of the sample by age and gender

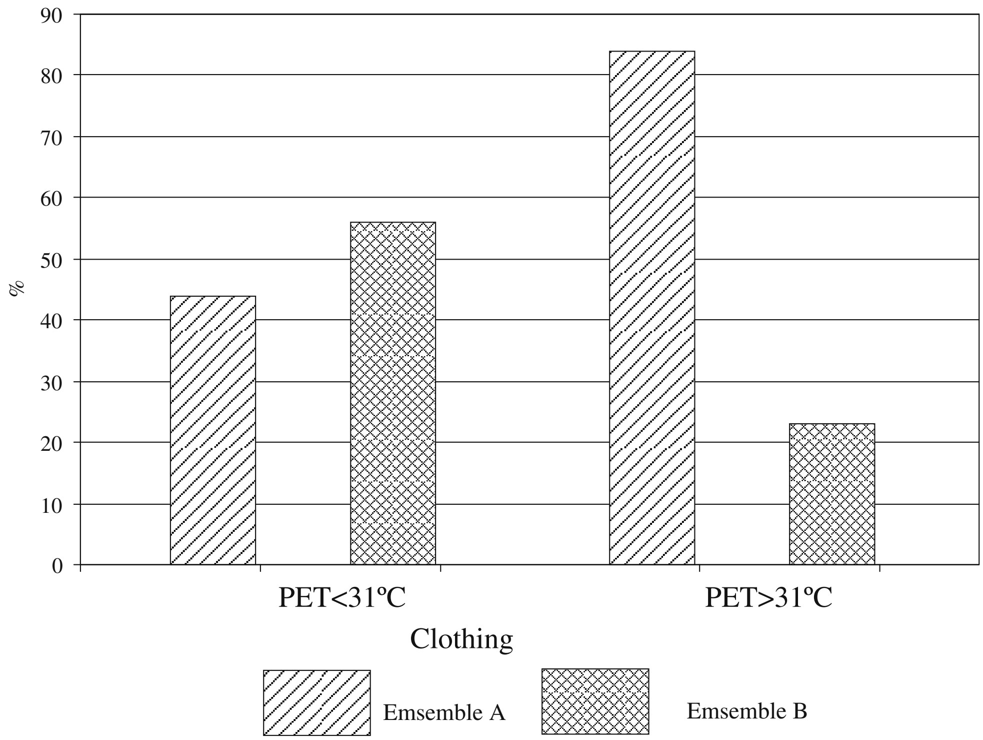

Fig. 7 Adaptation of clothing to thermal conditions

Nikolopoulou et al. (2001) found that people take action to improve their comfort conditions by modifying their clothing and metabolic rate, whereas Thorsson et al. (2004) found that the people who used the Slottsskogen Park in Goteborg, Sweden, improved their level of comfort, either consciously or unconsciously, by modifying their clothing, in order to continue to use the park when the thermal environment changed.

Perception of weather variables

The general thermal conditions (Table 5, question 21) and the various specific weather parameters (Table 5, question 19) were considered comfortable in almost all cases. However, some interviewees regarded a particular parameter as unpleasant (Fig. 8). This means that, even when the interviewees feel generally comfortable, their levels of satisfaction may vary depending on the parameter considered.

Table 6 Differentiation in the thermal isolation of clothing (clo units) between the two groups defined by the physiological equivalent temperature (PET) threshold

	<31°C	>31°C
Percentile 15	0.55	0.45
Average	0.67	0.58
Percentile 85	0.83	0.73
Standard deviation	0.16	0.11

Air temperature

The T_a, measured at the site of the interviews at a height of 1.5 m, varied between 18°C and 31°C throughout the entire set of observations. Despite the fact that 86% of the interviewees perceived these values as pleasant (question 19 and Fig. 8), it was found that, when questioned about the possibility of introducing changes in that variable (question 22), 17.5% stated that they would like the temperature to increase and 6.7% would like it to decrease. Only 3% of the interviewees singled out this variable as being the most unpleasant (Table 5, question 20 and Fig. 9).

There was no significant statistical relationship between the level of satisfaction with respect to T_a (Table 5, questions 19 and 22) and the actually recorded temperature values; this conclusion, together with some incongruity found in the answers to the different questions, could be a consequence of:

– the interference of other factors (other atmospheric variables and personal parameters) in the perception of air temperature;
– confusion between the perception of general thermal comfort and that of T_a, due to the very common preconceived idea that what an individual feels thermally is determined solely by the T_a.

The relationship between the perception of comfort derived from the T_a and that associated with v, analysed through Spearman's correlation coefficient, was found to be statistically significant and negative (−0.456, $P<0.01$). This

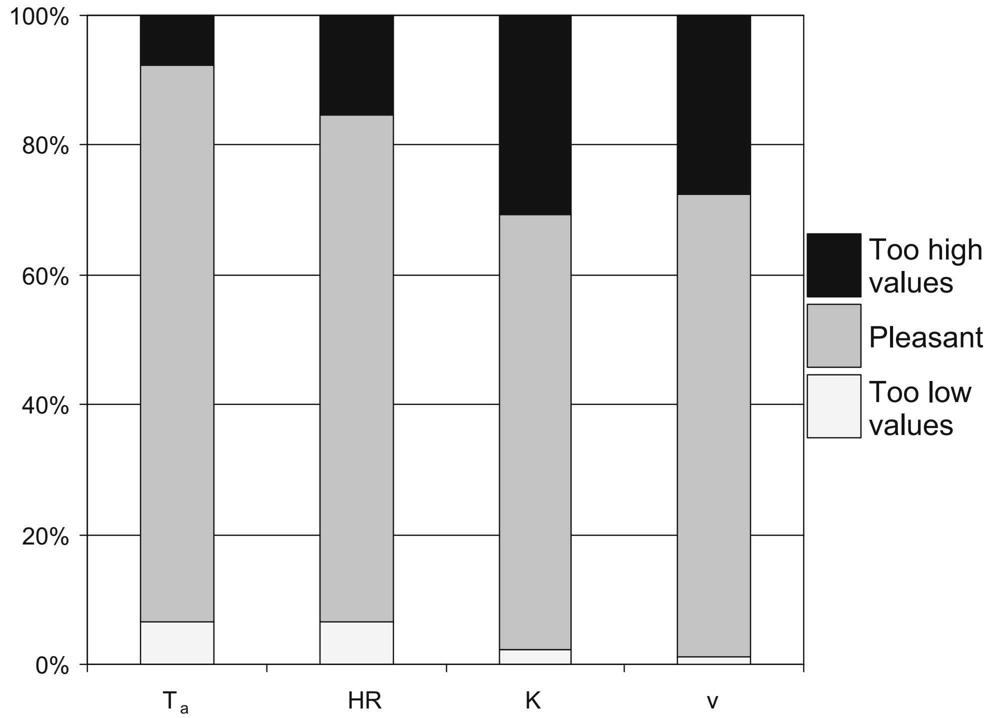

Fig. 8 Level of pleasantness declared by the interviewees with regard to each weather parameter

means that perception of a lower $T_a$corresponded to a high *v* and perception of the T_a as comfortable (or hot) was associated with a low *v*. These findings confirm the results of previous studies: Stathopoulos et al. (2004) found that people exhibit increased sensitivity to the wind force under colder conditions; Westerberg et al. (2006) also concluded that the environment is perceived as windier when the temperature is lower, and Nikolopoulou and Lykoudis (2006) stated that the effect of the wind is highly dependent upon the level of air temperature.

Air humidity

The values of RH ranged between 33% and 73%, while the vapour pressure varied between 13.5 and 20.2 hPa, with an average of 15.5 hPa; 15% of the interviewees declared that the atmosphere was very humid (Table 5, question 19), although only 5.5% considered that the humidity should decrease upon answering question 22 (Table 5). In answering question 20 (Table 5), only 1% of the individuals regarded humidity as the most uncomfortable variable (Fig. 9). These

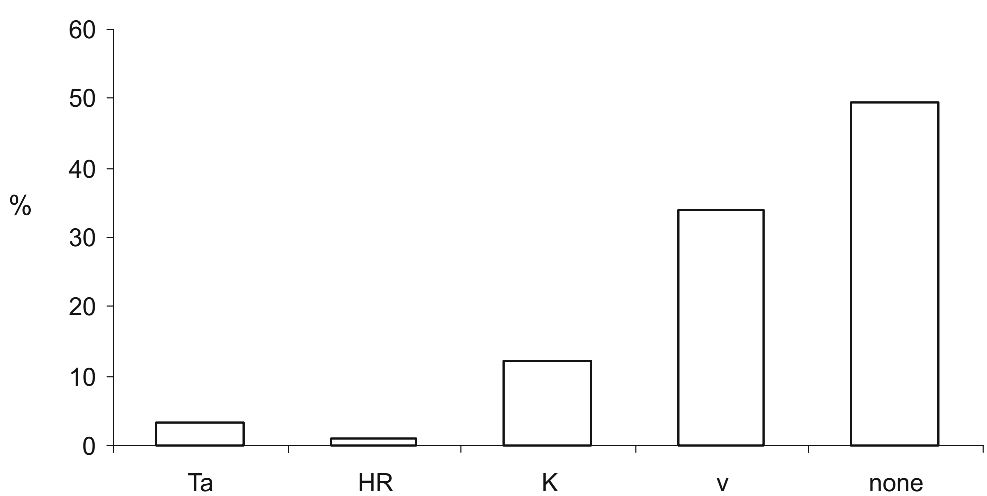

Fig. 9 Parameter perceived as most unpleasant by interviewees

results raise some doubts about the human ability to perceive humidity; indeed, as found by Nikolopoulou and Lykoudis (2006), people are not very good at judging changes in humidity levels, except under extreme conditions and in conjunction with air temperature.

Solar radiation

The global solar radiation on a horizontal surface measured in the study area varied between 273 W m^{-2} and 937 W m^{-2}. On answering question 19 (Table 2, Fig. 8), 30% of the interviewees considered the level of *K* to be too high (thus falling outside the comfort conditions), but only 19% stated that *K* should decrease in the answer to question 22. It is also important to state that 12% regarded this variable as being the most unpleasant (Fig. 9).

It was not possible to find any statistically significant relationship between the level of satisfaction declared by the respondents and the values of *K* measured on a horizontal surface. Although this type of record is the simplest to perform, it is an insufficient representation of the solar radiation received by the human body, which has more vertical than horizontal surfaces (Underwood and Ward 1966). A variety of methods aimed at assessing the solar input for the human body were discussed in Blazejczyk et al. (1993); however, the methods described there were considered too complex to be used in this study because of the large number of individuals, the diversity of exposure conditions and the position of the sun. For this reason, the radiation received by the human body (Kb) was estimated by adding the value of the global radiation falling upon a horizontal surface ($K\downarrow$) to the values of the global radiation falling upon vertical surfaces coming in from the west and the south, respectively (KW and KS). These three directions were chosen because they represent those from which direct solar radiation is most intense during the afternoon. These fluxes were weighted by the coefficients defined by Fanger (1972) for fluxes falling upon vertical and horizontal surfaces, depending on the position of the body (Table 7, Fig. 10).

Ultimately, for a person standing, the solar radiation reaching the human body (Kb) was calculated as:

$$\mathrm{Kb} = 0.06\ \mathrm{K}\downarrow +\ 0.22(\mathrm{KS} + \mathrm{KW})$$

Table 7 Weighting factors for individuals in standing and sitting positions (Fanger 1972)

Weighting factors	Standing	Sitting
Vertical surfaces	0.22	0.185
Horizontal surfaces	0.06	0.13

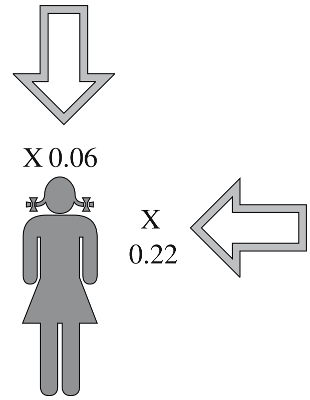

Fig. 10 Weighting factors of the various *K* fluxes (from different directions) that fall upon the (standing) human body

For a seated person, Kb was calculated as:

$$\mathrm{Kb} = 0.13\ \mathrm{K}\downarrow +\ 0.185(\mathrm{KS} + \mathrm{KW})$$

The values of Kb varied between 88 and 345 W m^{-2}. While K↓ decreased markedly throughout the afternoon as a result of the change in the height of the sun, Kb exhibited the highest values around 3 p.m. and decreased more gradually than K↓ (Fig. 11) because, as the height of the sun decreased, the horizontal component of the *K* flux became more important.

The relationship between Kb and the level of satisfaction with regard to solar radiation (question 19) was found to be statistically significant according to analysis of variance (F=4.6 for a significance limit of 3.95, with $P<0.05$). Table 8 shows a characterisation of Kb under situations of both pleasant and excessive solar radiation.

Wind speed

The level of wind-related comfort depends on both thermal and mechanical aspects. Although the conceptual distinction between these two variables seems very simple, the distinction between the contributions of the two to the level of comfort perceived by individuals is much harder.

Values of *v* ranged between 1.1 m/s and 3.7 m/s in 70% of cases (15th and 85th percentiles of the total set of observations), reaching a maximum value of 6.8 m/s; 71% of the interviewees considered these values as pleasant upon answering question 19, as opposed to 27% who considered it to be excessive (Table 5, Fig. 8), and 22% indicated in their answer to question 22 (Table 5) that reducing *v* would make them feel more comfortable.

As previously explained, *v* was measured every 30 s, which corresponds to three measurements during each interview. Some relevant differences in terms of the values of *v* could be found between respondents who characterised the wind as pleasant and those who regarded it as excessive. This differentiation increases if we consider the maximum wind speed (v_{max}) of the three observations

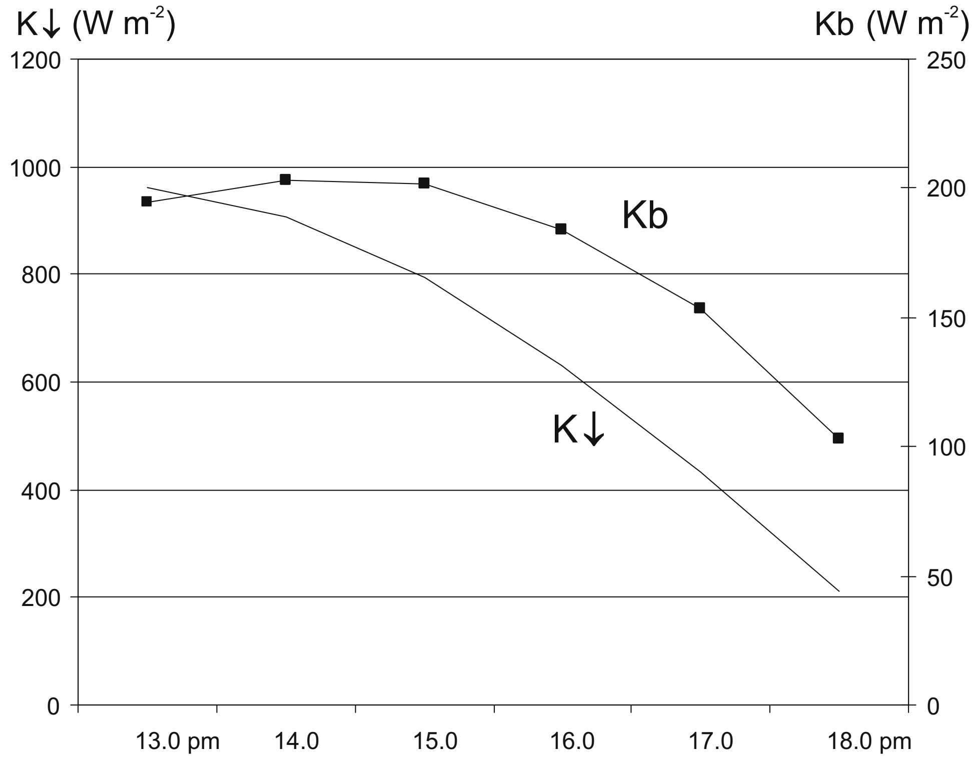

Fig. 11 Variation in solar radiation (K) and solar radiation reaching the human body (Kb) during the afternoon of 23 April 2006

instead of the average speed. However, the variability of the wind, and not just its speed, can also influence the level of (thermal and mechanical) comfort (Penwarden 1973; Mayer 1985, cited by Höppe 1988; ACSE 2004). The formula shown below is an attempt to combine the maximum speed and the variability of the wind, by adding the value of v_{max} to the standard deviation of the three observations (sv):

$$\nu\chi = \nu_{max} + s\nu$$

The differentiation of $v\chi$, in several classes of comfort, is statistically significant, with F=9.01 for a threshold of 6.93 and P<0.01. This association between v and the responses obtained from the interviews was the strongest among all the weather variables considered. With values of $v\chi$ lower than 2.25 m/s, no one claimed to feel uncomfortable, but with a $v\chi$ higher than 3.7 m/s, 40% of individuals regarded the wind as excessive, and the proportion rose to more than 50% for values of $v\chi$ above 6.9 m/s.

Table 8 Differences in solar radiation reaching the human body (Kb) between the respondents who regarded solar radiation (K) as pleasant and those who considered it excessive

Kb	Pleasant	Excessive
Percentile 15	149	214.1
Average	229.3	264.3
Percentile 85	309.1	326.9

Gender is another factor that clearly affects the level of comfort perceived by individuals in relation to v; 32% of the women declared v as unpleasant, as opposed to 24% of the men. Moreover, 44% of the women declared v to be the most uncomfortable variable, whereas only 21% of men said so. A dissimilar pattern was also found, depending on gender, with respect to the relationship between the level of comfort and $v\chi$, as shown in Fig. 12. This figure shows the variation in the percentage of individuals (women, men and total) that claimed to feel satisfied in relation to values of $v\chi$. It was found that an increase in the value of $v\chi$ leads to a rapid decline in the percentage of women regarding those conditions as pleasant, while the percentage of men is only slightly reduced. This means that women are more sensitive to wind than men, who, in turn, can feel comfortable under a wider range of $v\chi$ values. The values of R^2 demonstrate this difference, even though the R^2 value of the male population is still statistically significant (P<0.05). With values of $v\chi$ higher than 3.7 m/s, more than 50% of the women declared feeling uncomfortable, as opposed to only 27% of the men.

To our knowledge, no previous study has yet acknowledged these results, which seem to demonstrate that women exhibit a higher sensitivity to wind than men, or put forth any reasons to account for these differences. In the present study, only a slight difference was found between the mean clo values of men and women (0.6 and 0.7, respectively). Besides, only 4% of the women wore skirts at the time of the interview, leading to the conclusion that clothing cannot

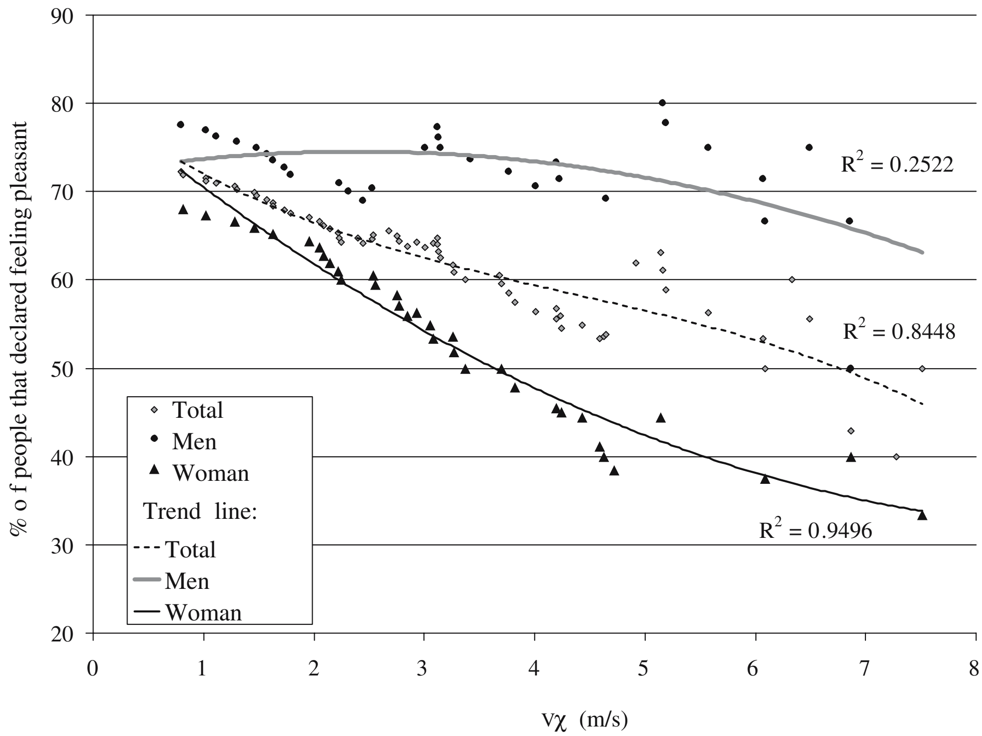

Fig. 12 Gender differences in the level of satisfaction with $v\chi$

account for the differences. Bearing in mind that the perception of the wind is closely linked to the perception of the air temperature (Nikolopoulou and Lykoudis 2006; Stathopoulos 2006), it is worth mentioning the results found by Mäkinen et al. (2006) in a study on outdoor exposure in the winter in Finland; although this latter study was conducted in a different climatic context, the authors found that men report being more exposed to the cold during their leisure time than women, which could be partially explained by preferences and cultural differences. Also, Fanger (1972) has argued that women are more sensitive than men to deviations from the thermal optimum.

Conclusion

This paper describes the methodology and the early results obtained from outdoor comfort surveys performed in an open urban area of Lisbon. The methodology applied proved to be appropriate to meet the project's requirements and it was demonstrated that the interview was feasible and easy to complete. The results presented have shed some light on the possible relationships between the various factors that influence outdoor climatic comfort, based not just on the calculation of comfort indices but, mainly, on the assessment of subjective parameters.

It was found that individuals interviewed under these specific environmental conditions could feel comfortable with much higher temperature values than those considered by traditional thermal comfort models. People are generally aware of the lack of control over the outdoor environment and they expect greater variability in the case of the atmospheric conditions than in that of an indoor environment. In addition, a "spontaneous" adaptation of clothing to the overall thermal conditions (as conveyed by the PET) was also observed: with PET values higher than approximately 31°C, the predominant type of clothing changes and clo values are reduced. It was also found that air temperature is difficult to perceive, because its perception is often confounded with that of the overall thermal environment and is modified by other parameters, particularly wind speed, for the examined conditions.

The perception of RH was also somewhat doubtful, taking into consideration that people are not easily capable of perceiving changes in humidity. The level of solar radiation perceived by the interviewees was not significantly related to the global solar radiation measured on a horizontal surface; on the other hand, it was found that the values of solar radiation that took into account the coefficients of incidence upon the human body, depending on the direction, were significantly related to the perception of this variable. Wind was found to be the most intensely perceived variable, usually in a negative way. Nevertheless, the majority of interviewees claimed to feel comfortable. The relationship between the percentage of individuals that regarded the wind as "uncomfortable" (because it was too windy) and the values of the wind speed was more significant when the extreme values and the variability of the wind were taken into account than when only average wind speed values were considered. An empirical formula ($v\chi$) was thus obtained that combined the extreme values of the wind speed with its variability and, when applied, it showed a statistically significant relationship with respect to wind perception by the interviewees. Women showed a stronger negative reaction to high $v\chi$ than men. Furthermore, a relationship of dependency was found between the perception of the wind and the air temperature: when the air temperature was perceived as cooler, the wind was more frequently considered “strong” or “too strong”; on the other hand, when the air temperature was regarded as “hot”, the wind was usually perceived as “comfortable”.

The findings of this experiment are consistent with the conclusions reached in previous studies. It has also become evident that there are specific methodological problems inherent in work of this kind: the capacity to distinguish between the several aspects that influence the perception of outdoor comfort; people find it difficult to unravel the thermal and mechanical effects of the wind, and the degree of influence of several atmospheric parameters on the general conditions of comfort.

In summary, the results presented here suggest that there is a relationship between outdoor climatic comfort, atmospheric parameters and the personal characteristics of individuals. The level of influence of each variable depends on specific conditions that require deeper analysis, with a larger sample and field validation. The experiment presented here provides a framework for further research on this subject, but it should be borne in mind that some adjustments are likely to be required, depending on the specific characteristics of the area and the season in which it is applied.

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