PLEA2009 - 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada, 22-24 June 2009

Green Space Influence on Thermal Comfort

Contrasting approaches in the assessment of conditions in Bragança (Portugal)

ARTUR GONÇALVES[1], ANTÓNIO RIBEIRO[1], LUIS NUNES[1], FILIPE MAIA[1] E MANUEL FELICIANO[1]

[1]Instituto Politécnico de Bragança, Portugal

ABSTRACT: Green Spaces are regarded as elements that can help to provide thermal comfort inside cities. To evaluate this influence both climate and personal variables must be investigated and evaluated taking into account different spatial layouts. Trying to address this complex reality, two different approaches were developed, using green spaces at the city of Bragança (Portugal) as case studies: green spaces surveys, addressing users, and structured experiments, controlling both individual and climatic variables. Field surveys proven to identify a narrow range of thermal sensations, thus limiting the analysis. Data from a structured experiment, conducted in early fall conditions, show the influence of different green space locations on both meteorological variables and thermal sensations. Amongst the evaluated variables, global radiation proves to be the most relevant variable influencing the perceived thermal sensations.
Keywords: Thermal Comfort, Outdoor Spaces, Green Spaces

INTRODUCTION

About three quarters of the European population live nowadays in cities [1], facing various environmental stresses in the form of poor air quality, excessive noise and uncomfortable thermal conditions. Urban greening has been widely recognised as a key factor to mitigate the adverse effects of urbanisation in a sustainable manner [2, 3, 4].

Green spaces characteristics include trees, soft surfaces and wind shelters that can influence thermal sensations by influencing such variables as solar radiation, temperatures of surrounding surfaces, air temperature, humidity and wind speed. Changes in these variables can have an important impact on individuals' perception of the quality of thermal environments.

Human thermal comfort depends on the superior climate and local weather conditions, but is strongly modified by cities (e.g. [5]). As thermal comfort is influenced by both thermal parameters and human heat balance [6], diverse empirical thermal indices were developed first addressing indoor conditions like, for instance the balance model is the comfort equation defined by Fanger [7], developed for the calculation of the indices "Predicted Mean Vote" (PMV) and "Predicted Percentage Dissatisfied" (PPD), however, this indicator may not be appropriate for the assessment of short-term outdoor thermal comfort [8] specially considering the differences in solar radiation and wind intensity [9]. More universally applicable than these models are those that enable to predict "real values" of thermal quantities of the body, e.g. skin temperature, core temperature sweat rate or skin wetness, as it is the case of the thermal index "Physiologically Equivalent Temperature" PET [6], which considers experiences with the thermal index "New Effective Temperature" ET [10]. PET values around 20 °C indicate that the thermal environment is perceived by people as thermally comfortable.

When evaluating individual thermal comfort, a scale consistent with the range of sensations perceived is normally used for research proposes, here called Thermal Sensations (TS), and allows interviewees to express both cold (negative values) and hot (positive values) sensations, and using zero as the state of thermal comfort equilibrium.

Only few studies address the influence of green spaces on micro-scale conditions, establishing relation with the perceived thermal sensations. Amongst these studies two different approaches can be found: field surveys, concentrating on evaluating casual users' perceptions and attitudes towards thermal comfort conditions (eg. [11]); and Structured experiments, by controlling both individuals and locations characteristics (eg. [12]).

As part of the ongoing research entitled Green Spaces Impact on Urban Environmental Quality (POCI/AMB/59174/2004), both users' surveys and structured experiments are being developed, trying to establish relation between green spaces characteristics and thermal comfort. This paper presents some of its preliminary results from these contrasting approaches and identifies some of the main advantages and disadvantages of these contrasting methodologies.

METHODS

The city of Bragança (41º 48□ N, 6º 46□ W, 680 m a.m.s.l.) is located in north-eastern Portugal. The climate of the region is characterised by a cold rainy winter, receiving about 70% of the 758 mm of annual rainfall, and relatively short (June to September) hot and dry summer. The mean annual temperature is 12.2ºC.

Field surveys This study was carried out in four different green spaces, evaluating both thermal perceptions, by means of using questionnaires, and thermal conditions evaluation by measuring meteorological variables such as air temperature (Ta), relative humidity (RH), wind speed (V) and direction, global solar radiation (St) and mean radiant temperature (Tmrt). A mobile meteorological station (Fig. 1) equipped according to Table 1 was used to measure meteorological variables near the individuals when they were filling in the questionnaires. Interviewers approached the users assessing their thermal sensation (TS), while gathering individual parameters (age, gender, clothes, level of activity, etc.).

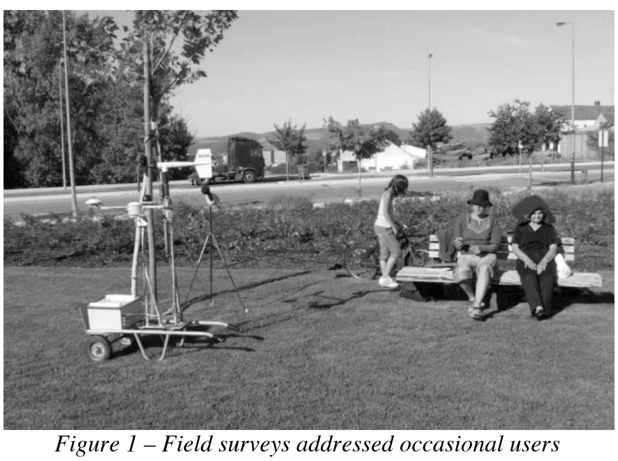

Figure 1 – Field surveys addressed occasional users

Structured experiments This study was carried out in four different locations (Fig. 2) on a restricted area (0,5 Ha.), under different microclimate conditions, with the objective of evaluating the influence of variables (the same ones as in field surveys) on thermal sensation (TS). The locations had the following conditions: (A) Shadow under tree, over bare soil and near a water pound; (B) Shadow under artificial cover and over grass; (C) Sun exposure near wind shelter over grass; (D) Sun exposure over pavement.

A total number of 12 individuals participated in this study (six man and six women), grouped around four age groups (20-30; 31-40, 41-50 and over 50 years) and wearing jeans and a white t-shirt. Each participant filed in a questionnaire, assessing individual perceptions on thermal sensation, every time they were on a different location. Each group, with three participants, stayed seated in each location for 15 minutes (10 minutes adjusting to local conditions and five minutes filling in the questionnaire), changing location after time had passed, moving to the next location in a rotation scheme. After approximately 60 minutes, every group had gone through the four locations. This procedure was carried out three times during the same day, starting at 9 a.m. and finishing at 6 p.m.

Figure 2 – Four situations used in structured experiments

Meteorological measurements and instrumentation: A micrometeorological station equipped according to Table I was used to measure air temperature, globe temperature, relative humidity, wind speed and wind direction, this equipment was used in both studies.

Table 1: Measured meteorological variables and instruments.

Variable	Instrument
Air temperature, T_a	Campbell Sci., CS215
Globe temperature, T_g	Campbell Sci., 107 Thermistor
Relative humidity, RH	Campbell Sci., CS215
Wind speed, V	R.M. Young, 05103
Global solar radiation, S_t	Kipp & Zonen, CM6B

Data were collected and averaged using the CR10X data logger (Campbell Sci.). The sampling interval was one minute for all the weather variables. In the structured experiments, additional temperature and relative humidity in the four locations were measured and collected using a compact data logger (Testo, 175-

H1). Wind speed near wind shelter (C) was measured using a cup anemometer (Thies Clima). Transmitted radiation was measured under the tree shadow using a solarimeter tube (Delta-T Devices) placed 0,2 meters above ground.

The mean radiant temperature (T_{mrt}) was calculated in both studies by considering globe temperature and wind speed according to equation (1) [13]:

$$T_{mrt} = \left[(T_g + 273.15)^4 + \frac{1.1 \times 10^8 V^{0,6}}{\varepsilon D^{0,4}} (T_g - T_a) \right]^{\frac{1}{4}} - 273.15 \quad (1)$$

T_g – globe temperature (ºC)
T_a – air temperature (ºC)
V – Wind speed (ms^{-1})
ε – globe emissivity (0,95)
D – globe diameter

The empirical derived parameter 1.1 x 10^8 and the wind exponent ($V_a^{0.6}$) together represent the globe's mean convection coefficient (1.1 x 10^8 $V_a^{0.6}$).
Data were analyzed using SPSS 16.0 Software.

RESULTS AND DISCUSSIONS

Field Surveys Field surveys were carried out in summer conditions (June, July and September 2007), evaluating four different green spaces: two of them traditional and rather small parks, with large amount of shadow; and two more recent and large parks, with few shadow. A total amount of 194 surveys were carried out, at approximately equal proportions between green spaces, from 10 to 20 am.

To assess thermal Sensation (TS) individuals rated their thermal sensation raging from -2 (very cold) to +2 (very hot), as the middle value (0) meaning a thermal comfort equilibrium.

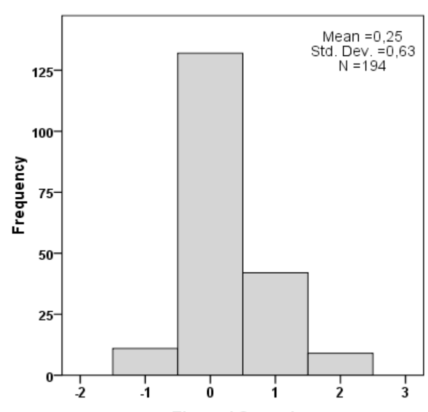

Figure 3 – Absolute frequency in Thermal Sensation values for the field survey

Results show a major tendency towards a comfort status (Fig. 3), accountable for almost two thirds of the situations, as very few (in the case of very hot) or none answers (in the case of very cold) were given stating extreme sensations, despite the fact that surveys took place in conditions that could be generally described as ranging from cool to very hot days (just below 40ºC).

Amongst the factors that may have influenced these results are: the narrow amplitude of the scale, reducing the amount of possible options for the description of individual perceptions; alongside with users' ability to choose when and where to stay in green spaces, looking for shadow elements in hot periods and sun exposure in more mild conditions and thus reducing the chances for extreme uncomfortable situations.

Table 2: Average meteorological variables and PET for different Thermal Sensations

	TS	Ta (ºC)	RH (%)	V (m/s)	St (Wm-2)	Tmrt (Cº)	PET
Cool	Mean	21.25	36.84	1.06	109.20	29.15	21.29
	Std. Error of Mean	0.75	2.96	0.15	35.66	3.32	1.38
	N	11	11	11	11	11	11
Neutral	Mean	23.42	36.30	1.08	296.98	39.74	27.38
	Std. Error of Mean	0.34	0.79	0.05	26.54	1.08	0.53
	N	132	132	132	132	132	132
Warm	Mean	25.41	31.60	1.16	362.65	44.08	30.76
	Std. Error of Mean	0.60	1.36	0.08	47.29	1.73	0.99
	N	42	42	42	42	42	42
Very Hot	Mean	24.45	29.87	1.08	479.54	48.96	32.47
	Std. Error of Mean	1.33	2.73	0.15	117.99	4.35	2.39
	N	9	9	9	9	9	9
Total	Mean	23.77	35.01	1.09	309.02	40.51	28.00
	Std. Error of Mean	0.28	0.66	0.04	21.93	0.90	0.47
	N	194	194	194	194	194	194

Data shows that TS tend to increase alongside radiation and radiant temperature (Table 2), however under those conditions it wasn't possible to consistently determine the driving elements influencing TS.

Structured experiment The structured experiment took place in early fall conditions (October 2008), in three different time frames (10:08-11:03; 14:05-15:05; 16:20-17:20). A total 144 surveys were filled, 36 in each location.

Table 3 presents the differences in the variables considering the four different locations, showing: small differences concerning T_a; higher RH is found in place A (near a water pound), as place D had the lowest values (over pavement); (as expected) wind shelter helped lowering wind speed in location C; T_s values were considerably lower in shadow locations, specially tree shadow, as this element proved to be more effective cooling surfaces in the surrounding, lowering T_{mrt} in a more efficient manner. When applying PET index, the influence of T_{mrt} determined that higher values were found in sun exposure location (C and D), as opposite to lower values found under shadow locations, especially under tree shadow (A).

Table 3: Average meteorological variables and PET for different locations

Location		Ta (ºC)	RH (%)	V (ms-1)	St (Wm-2)	Tmrt (ºC)	PET
Shadow Under Tree (A)	Mean	21.79	48.37	0.87	118.03	27.76	21.21
	Std. Error of Mean	0.36	2.75	0.03	5.41	0.32	0.30
Shadow Under Artificial Cover (B)	Mean	21.79	41.29	0.87	174.44	40.71	26.77
	Std. Error of Mean	0.36	2.46	0.03	6.66	1.14	0.70
Sun Near Wind Shelter (C)	Mean	21.94	36.11	0.68	488.62	46.81	30.92
	Std. Error of Mean	0.51	2.36	0.05	19.09	0.58	0.40
Sun Over Pavement (D)	Mean	21.94	42.10	0.87	488.62	46.80	29.82
	Std. Error of Mean	0.51	2.56	0.03	19.09	0.61	0.44
Total	Mean	21.87	41.97	0.83	317.43	40.52	27.18
	Std. Error of Mean	0.22	1.31	0.02	16.03	0.74	0.40

Under these experimental circumstances, participants were asked about their thermal sensations in a scale ranging from very cold (-3) to very hot (+3) (this scale was adjusted after the initial field survey). Answers given covered the entire range of TS (Fig. 4).

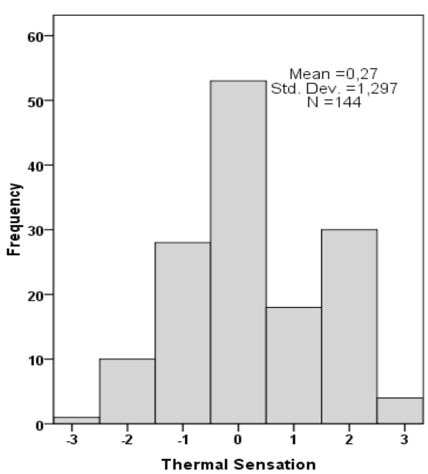

Figure 4 – Absolute frequency in Thermal Sensation values for the structured experiment

As it is clear from Fig. 5, differences can be found concerning thermal sensations between the four different locations, as participants felt predominant warm sensations under sun exposure, opposite to neutral to cool conditions found under shadow.

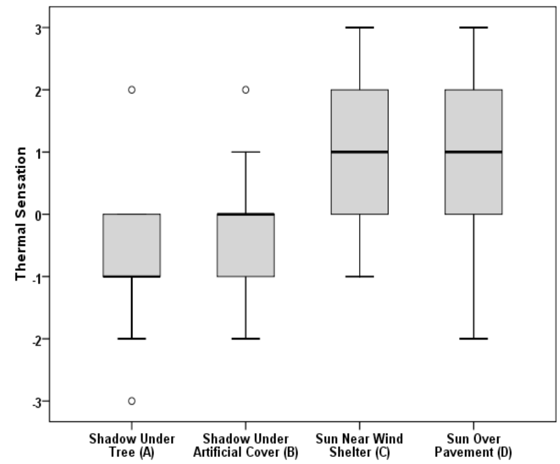

Figure 5 – Thermal Sensation frequencies at the different locations

Fig. 6 shows the differences in global radiation in relation to different shadow and sun exposure conditions. Radiation was consistently higher in sun exposed locations until sunset, as shadow elements helped lowering participants' thermal sensation. This kind of effect had both positive and negative effects, as its influence made shadow locations cooler, thus meaning that participants could either find shadow locations more comfortable, in opposition to warm to hot under the sun locations, or felt these places were rather cool when finding themselves comfortable under sun exposure.

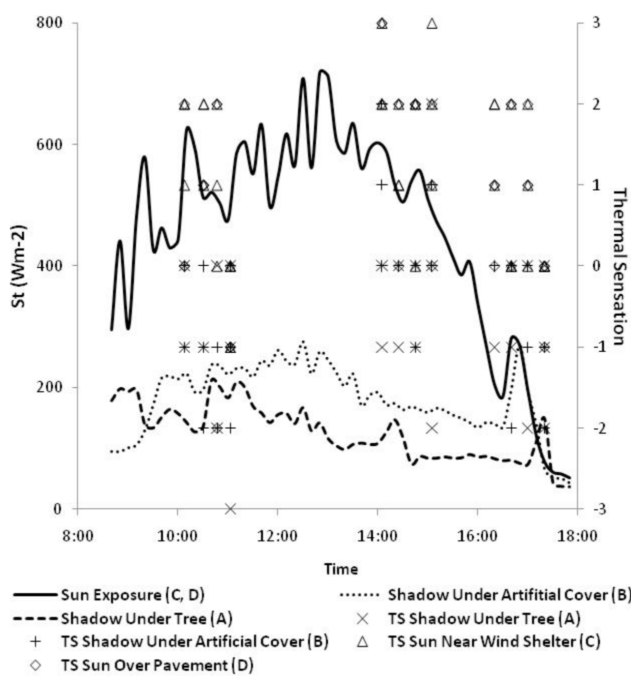

Figure 6: TS of subjects with measured solar radiation in different shadow conditions and in sun exposure

Using Pearson Correlation for evaluating Thermal Sensation relations with the different independent variables, including Ta, V, St, RH and Tmrt, a large correlation could be found with global radiation (St) (ϱX,Y = 0,714) and radiant temperature (RH) (ϱX,Y = 0,593) thus stating the strong relation with these variables.

While using linear regression (stepwise), trying to establish an experimental formula expressing Thermal Sensation in relation to climatic variables, a medium linearity was found with the global radiation (St) and Relative Humidity (RH).

TS=-0,642+0,005St-0,013RH

With a R2 value of 0,533.

This regression formula reflects the important effect of radiation on Thermal Sensation, but it also suggests a cooling effect resulting from higher humidity. Although differences were found concerning RH between the locations (see table 2), this relation might be just an 'error' resulting from the very small number of human subjects, and may not represent the real independent effect of the humidity, as it was expected that higher humidity would increase the sensation of warmth [12].

CONCLUSIONS

As expected, results so far suggest that radiation is an essential parameter influencing outdoor thermal sensation. Diverse elements inside Green spaces, may offer complementary conditions that can have a positive impact on Thermal Sensation, as opposite to more artificial locations.

Evaluating the two different approaches used in thermal comfort studies, some conclusions can be drawn:

- While field surveys offer a more natural approach, studying individual sensations in common behaviors, they may reflect choices that can restrain thermal sensations, especially concerning clothing, metabolism and time spent on different locations.
- Structured experiments offer a greater control over both personal (clothing, metabolism, age and gender ratio) and environmental conditions (testing contrasting conditions in equal proportions). However, it is difficult to engage as many users, narrowing the amount of users evaluated.

Recognizing the added value of this kind of methodology, additional structured experiments will be conducted within the course of this project, taking place in both spring and summer conditions, as further data may add relevant elements, helping to understand the influence of green spaces on thermal comfort and offering different seasonal approaches. An additional goal for this research will be to provide useful indications for planners and designers that can improve thermal comfort and thus promoting social interaction on these spaces.

ACKNOWLEDGEMENTS. The authors thank the National Scientific Foundation of Portugal (FCT) for the financial support given to project GreenUrbe (PPCDT/AMB/59174/2004). Thanks must also go to the volunteer participants in this research.

REFERENCES

1. UNEP (2007). *World Urbanization Prospects: The 2007 Revision*. Report from the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat.
2. Bolund P. and Hunhammar S (1999). Ecosystem services in urban areas. *Ecological Economics*. 29: p. 293-301.
3. De Ridder K., Adamec V., Bañuelos A., Bruse M., Bũrger M., Damsgaard O., Dufek J., Hirsh J., Lefebre F., Pérez-Lacorzana J. M., Thierry A. and Weber C. (2004). An integrated methodology to assess the benefits of urban green space. *Science of Total Environment*. 334: p. 489-497.
4. Nowak D. J., Crane D. E. and Stevens J. C. 2006. Air pollution removal by urban trees and shrubs in the united states. *Urban forestry & Urban Greening*. 4: p.115-123.
5. Oke, T.R., 1987: *Boundary layer climates*. Methuen & Co. Ltd., London.
6. Höppe, P., 1999: The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *Int. J. Biometeorol*ogy. 43: p.71-75.
7. Fanger, P.O. 1972. *Thermal Comfort*, McGraw-Hill, New York, USA
8. Thorsson S., Lindqvist M. e Lindqvist S., 2004. Thermal bioclimatic conditions and patterns of behaviour in an urban park in Goteborg, Sweden. *Int J Biometeorology*, 48: p.149–156.
9.Huang, J., (2007) Prediction of air temperature for thermal comfort of people in outdoor environments. *Int J Biometeorology*, 51: p.375–382.
10. Gagge, A.P., Stolwijk, J.A.J., Nishi, Y., (1971). An effective temperature scale based on a simple model of human physiological regulatory response. *ASHRAE Trans*. 77: p. 247-257.
11. Nikolopoulou, M. and Steemers, N., (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings*, 35: p. 95–101.
12. Givoni B. M. N., Saaroni H., Pochter O., Yaacov N. F. Y. and Becker S. 2003. Outdoor comfort research issues. *Energy and Buildings*, 35: p.77-86.
13. Thorsson, S.; F. Lindberg; I. Eliasson and B. Holmer, (2007). Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology*, 27: p. 1983-1993.