Design to Thrive - PLEA 2017

Proceedings of 33rd PLEA International Conference
Design to Thrive
Edinburgh, 2th-5th July 2017
PLEA 2017 Conference www.plea2017.net

Published by NCEUB 2017
Network for Comfort and Energy Use in Buildings http://nceub.org.uk
to download go online to www.nceub.org.uk

All contributions to the 2017 PLEA Conference included herein were independently peer reviewed as a full paper, prior to publication.

ISBN 978-0-9928957-5-4

Evaluation of the PET thermal comfort index calibration methods used in Brazil

Simone Queiroz da Silveira Hirashima[1], Daniele Gomes Ferreira[2], Eleonora Sad de Assis[3], Lutz Katzschner[4]

[1] Department of Civil Engineering, Federal Center of Technological Education of Minas Gerais, Belo Horizonte, Brasil, simoneqsh@civil.cefetmg.br
[2] Department of Technology of Architecture and Urbanism, School of Architecture, Federal University of Minas Gerais, Belo Horizonte, Brasil, dani.gferreira@yahoo.com.br
[3] Department of Technology of Architecture and Urbanism, School of Architecture, Federal University of Minas Gerais, Belo Horizonte, Brasil, eleonorasad@yahoo.com.br
[4] Institut Urbane Entwicklungen / Environmental Meteorology, University Kassel, Kassel, Germany, katzschn@uni-kassel.de

Abstract: A calibrated thermal comfort index, which can represent human thermal sensation in a numerical way, is a valuable tool for evaluating thermal conditions in urban areas. Brazil, a continental size country, presents eight different climate zones according to its bioclimatic zoning standard. Due to its area extension and climate diversity, thermal comfort indexes must be calibrated to each city to better represent the different thermal sensations of each local population. In Brazil, the Physiological Equivalent Temperature (PET) index, widely applied in outdoor evaluations, has already been calibrated for some cities, as: São Paulo (2008), Belo Horizonte (2010; 2016), Salvador (2010) and Curitiba (2012), by using different methodologies, during both data collection and statistical treatment stages. Considering the need to standardize the calibration methods, the aim of this work is to present the results of these calibrations, to compare them and to analyze the methodologies used in each calibration process, pointing out specific details of them. It is expected to come up with recommendations to forthcoming calibrations, making it possible to compare results and to facilitate future applications of the PET index as an evaluation tool for assessing thermal conditions in urban planning projects.

Keywords: Outdoor thermal comfort, PET index, thermal sensation, calibration methods

Introduction

The design of open spaces in cities can contribute to stimulate the use of these areas, which additionally could provide a better quality of life for the population. In order to suitably plan these spaces, an important aspect to account is the outdoor thermal condition. It includes the consideration of the climate of cities, but also an evaluation of the different microclimate related to the different urban structures, which can influence the thermal comfort in open spaces. Besides, it is important to regard the human being as a reference.

However, the lack of information on the subjective perception and evaluation of comfort conditions in outdoor spaces makes it difficult to support planners in their decision-making (Nikolopoulou & Lykoudis, 2006). In this context, one way to contribute is by using outdoor thermal comfort indices, which integrate thermophysiological and subjective parameters allowing the estimation of the thermal environment from a human approach. The Physiological Equivalent Temperature index (PET) is one of them and it is widely applied in the evaluation of outdoor thermal conditions.

PET (°C) is an index used to describe the thermal situation of a person, combining climatic parameters (mean radiant temperature, air temperature, wind speed and relative humidity), person's activity and type of clothing (Höppe, 1999). Furthermore, there are evidences that psychological processes based on sociocultural processes can influence the evaluation of a place in terms of thermal, emotional and perceptive aspects (Knez &Thorsson, 2006). Available choice, environmental stimulation, thermal history, memory effect and expectations also play an important role in the subjective evaluation of the microclimate conditions (Nikolopoulou et al., 2001). Considering the influence of all these parameters, the comfortable thermal conditions are not the same worldwide. Classes of thermal perception, including the comfort zone, can differ according to the local climate because people are adapted to different climatic conditions. Therefore, it is important to calibrate the index to each different place and culture, also considering these psychological processes.

The PET calibration process aims to determine representative intervals of thermal comfort conditions in order to predict thermal sensation according to an assessment scale. For this, two types of data are collected simultaneously: microclimatic parameters (air temperature, relative humidity, mean radiant temperature and wind velocity, obtained from meteorological measurements according to ISO 7726) and subjective thermal perception responses of acclimatized pedestrians, obtained from structured interviews. A scale of seven-point categories is normally used: +3 (Hot); +2 (Warm); +1 (Slightly Warm); 0 (Comfortable); -1 (Slightly Cool); -2 (Cool) and -3 (Cold) (ISO 10551).

In Brazil, due to its territory extension and climatic diversity, differences between the cities and their population must be considered when analyzing thermal comfort and thermal sensations in open spaces. According to the national technical standard NBR 15220-3 (ABNT, 2005), the country is divided into eight zones relatively homogeneous as to their climatic type. This emphasize the relevance and the need to consider the specific climatic and microclimatic conditions of each place together with the acclimatization process of the local population in order to get to know the specific thermal comfort zones of each locality.

Guided by the search of this knowledge, Brazilian researchers are performing calibrations of the PET index for urban spaces. They had already done it for four cities: São Paulo (Monteiro, 2008), Belo Horizonte (Hirashima, 2010; Hirashima, 2016 et al.; Hirashima, Assis, Nikolopoulou, 2016), Salvador (Souza, 2010) and Curitiba (Rossi, 2012). However, the studies adopted different methodologies in the calibration process, which make it difficult to compare the results and to apply them with planning purposes. In this context, this study aimed to analyze the methodologies already used in Brazil, to show the results of these calibrations, to compare them and to show their singularities. The standardization of the calibration method, at a national level, is an important tool to obtain comparable thermal comfort zones, which can be used in the prediction of thermal perception of the population. This will help in obtaining a more accurate assessment of the urban microclimates, and will contribute to a deeper understanding of issues related to urban thermal comfort in the different Brazilian climatic zones.

Study areas

The PET index calibrations were carried out in four Brazilian cities: Belo Horizonte, Curitiba, Salvador and São Paulo. Table 1 shows some information about location, population and climatic classifications (based on Köppen and on climatic Brazilian zones) of each of these cities. Belo Horizonte and São Paulo are located in the southeast and are classified in the same climatic zone according to ABNT (2005), however the cities differ in terms of temperatures and wind speed – São Paulo has lower temperatures and higher wind speed. Curitiba is the southernmost city among the studied cities. It presents the least mean and minimum temperatures and the highest temperature amplitude. São Paulo is the most populous city, while Curitiba has the smallest population. Salvador is situated in the northeast of the country and it is the only city located on the coast. It has the highest values of mean temperature, relative humidity and wind speed (Table 2).

Table 1. Summary of information of the cities.

City	Location	Population (IBGE, 2010)	Köppen classification	Climatic zone (ABNT, 2005)
Belo Horizonte	19°49'S, 43°57'W	2,375,151	Aw / Cwa	3
Curitiba	25°25'S, 49°16'W	1,751,907	Cfb	1
Salvador	12°58'S, 38°30'W	2,675,656	Af	8
São Paulo	23°32'S, 46°38'W	11,253,503	Cwa	3

Table 2. Climatological data of each site (period from 1961 to 1990)[1]: mean temperature (Tm), minimum temperature (Tmin), maximum temperature (Tmax), relative humidity (RH) and wind speed (W). The elevation corresponds to the meteorological stations.

City	Elevation (m)	Tm (°C)	Tmin (°C)	Tmax (°C)	RH (%)	W (m/s)
Belo Horizonte	915,0	21.1	16.7	27.1	72.2	1.52
Curitiba	923,5	16.8	12.5	23.1	80.7	2.27
Salvador	51,4	25.3	22.7	28.2	80.9	2.28
São Paulo	792,1	19.2	15.5	24.9	78.4	2.67

[1]INMET, 2009

Calibration of the PET index in Brazil: comparison of methodologies

In Brazil, the PET index has already been calibrated by applying different methods of collection and statistical treatment of data . In the calibration processes, during the data collection stage, measurements of microclimatic variables are conducted simultaneously with the application of questionnaires. These questionnaires are used to collect individual and subjective variables regarding thermal perception. Differences are evident in the sample size, target population, time and number of days in which the data collection occurred, study areas and measurement point definition, and so on.

Table 3 presents a summary of information about the methodologies used in the data collection stage of the PET calibration studies. IIt shows that the data collection procedures differ in most of the aspects considered, but they still have some similarities. The method used in Belo Horizonte in the years of 2009/2010 and in Salvador were almost the same, because these studies took part in the same research project. The only difference between them is the time of day in which field surveys were carried out. The calibration process used in São Paulo, on the other hand, is quite different from the others, because it was carried out in the Campus of the São Paulo University (USP). Therefore, the location of the measurement points are particular and the students were the target population.

Table 3. Summary of PET calibration studies.

City	Number of interviews	Age of interviewers	Number of days	Sites of interviews	Time of the day	Measurement places	Year
Belo Horizonte[1]	944	20 to 59	8	2 squares	morning and afternoon	2 points (sun and shadow)	2009/ 2010
Belo Horizonte[2]	1,182	20 to 59	10	2 squares	morning and afternoon	2 points (sun and shadow)	2009/ 2010
Belo Horizonte[3]	1,690	20 to 59	4	2 squares	morning and afternoon	2 points (sun and shadow)	2013
Curitiba	1,685	13 to 91	15	15 points along streets	morning and afternoon	2 points (not specified)	2009/ 2010
Salvador	1,002	20 to 59	8	2 squares	afternoon	2 points (sun and shadow)	2009/ 2010
São Paulo	1,800	not specifie d	4	3 points in the Universit y Campus	morning	3 points (1 in the sun, 1 bellow trees, 1 bellow a tensile cover)	2005/ 2006

[1] Hirashima, 2010.
[2] Hirashima et al., 2016.
[3] Hirashima, Assis, Nikolopoulou, 2016.

The number of valid interviews is different between each study, but they do not have a correspondence with the population size. For Belo Horizonte, the PET index has been calibrated three times. The results of 2010 considered a sample of 944 interviewees, but winter temperatures were higher than expected for this season, making it impossible to measure low temperatures. Hirashima et al. (2016) extended the sample used in 2010 by Hirashima (2010), totalizing 1,182 interviewees, by carrying out one more field survey in the subsequent winter. Hirashima, Assis, Nikolopoulou (2016) performed a new and more recent study, with a sample of 1,690 interviewees. In this latter calibration, a larger sample and a wider range of microclimatic data, especially in cold thermal conditions were considered. The total number of valid interviews, defined by sampling processes, conducted in the other cities was: 1,800 in São Paulo; 1,002 in Salvador and 1,685 in Curitiba

All the surveys were carried out only during daytime and it is possibly not representative of the range of temperatures that can occur in each city. The point in which measurement equipment was placed is another aspect to be observed. In the case of the study carried out in Curitiba, the place of measurement was not specified, but it is important that the place where the measurements are carried out be linked to the place where the interviews are done. In this city, the age of the interviewees diverges from the sample of Belo Horizonte and Salvador and this could have an impact on calibration due to the different thermal perception of young and old people.

Besides standardized, it is of ultimate relevance that, when more than one equipment is being used, it is important to certify that their measures are the same and the equipment used is also gauged between them. This detail, in fact, is shown in the works.

Some details such as the method used to calculate the values of the PET index are hardly mentioned in the studies. About it, Hirashima (2010) presented a comparison of two methods of calculation of PET values: a) using the software Rayman 1.2®, which applies specific data for each individual of the sample, and b) using the software developed by the University of Freiburg, the version of Holst (2007), applying default personal data. She concluded that the values generated by these two softwares, in this case, differ little. However it shows that it is important to demonstrate how it is calculated.

Considering the methodologies applied, in all studies, after data collection, the calculated value of the PET index is then related to the thermal sensation categories in a seven-point scale, ranging from hot to cold, with a neutral comfortable range. Statistical processes used normally adopt these two variables: the dependent variable, that is the thermal perception, a categorical variable with seven categories; and the independent variable, that is the PET Index, a continuous numeric variable.

At this stage, data can either be analyzed by each of the categories considered in the forms, or be recategorized. Regarding the precise definition of all categories of thermal comfort as considered in the seven-point scale (ISO 10551), the studies of Hirashima (2010), Hirashima et al. (2016) and Souza (2010) found that the small seasonal and diurnal thermal variation together with the prevailing thermal stress due to the hot conditions throughout the year have a great influence on thermal perception of acclimatized people. It is assumed that this situation could mask thermal perception, making it difficult to determine precise ranges for all the categories, specially for "slightly warm" and for all the categories related to cold thermal conditions ("slightly cool", "cool" and "cold"). Although the different climatic zones of Belo Horizonte and Salvador, both Hirashima (2010) and Souza (2010) did not manage to delimit "slightly warm". This was one reason why Hirashima, Assis and Nikolopoulou (2016) considered only the three categories presented ("cold", "comfort" and "hot"), in order to better define the ranges. Rossi (2012) also used only 3 categories in her results. Both Hirashima (2010) and Souza (2010) did not manage to delimit categories related to cold conditions, due to the lack of climatic data measured in this thermal condition.

The statistical methods used to determine the thermal comfort ranges in the cited studies were: iterative method (Monteiro, 2008), ordinal logistic regression (Hirashima, 2010; Hirashima et al., 2016; Hirashima, Assis, Nikolopoulou, 2016), decision tree (Souza, 2010) and Linear Discriminant Function (Rossi, 2012). The complexity and the great number of variables involved in human thermal comfort evaluation of urban environments require the use of multivariate data analysis for interpreting field research results. The methods ordinal logistic regression, decision tree and linear discriminant function are suitable multivariate techniques. However, further studies are still necessary to point out the most suitable multivariate technique must be used in the statistical treatment.

Results of the calibrations

The results of the calibrations for the Brazilian cities mentioned above are presented in the Table 4:

Table 4. Results of PET calibrations. The values of the categories are expressed in °C of PET.

References / City	Categories						
	+3	+2	+1	0	-1	-2	-3
	Hot	Warm	Slightly warm	Comfor-table	Slightly cool	Cool	Cold
Belo Horizonte[1]	>35	31 - 35		<30			
Belo Horizonte[2]	>36	32 - 35	31	16 - 30	13 - 15	<12	-
Belo Horizonte[3]	-	-	>27	19 - 27	<19	-	-
Curitiba	-	-	>23	18 - 23	<18	-	-
Salvador	>34	29 - 34	27 - 29	<27	-	-	-
São Paulo	>43	>31	>26	18 - 26	<18	<12	<4

[1] Hirashima, 2010.
[2] Hirashima et al., 2016.
[3] Hirashima, Assis, Nikolopoulou, 2016.

The calibration results presented in Table 4 shows that the comfortable ranges established by Monteiro (2008) and Hirashima, Assis, Nikolopoulou (2016) are quite similar, presenting equal amplitude. These ranges were established to São Paulo and to Belo Horizonte, respectively, cities located in the same climatic zones. The ranges defined by Souza (2010) are shifted to warmer thermal conditions, when comparing to the other results. This may be attributed to the warmer thermal conditions characteristic of Salvador climatic zone. The comfortable band narrowing which can be observed in the study carried out by Rossi (2012) to Curitiba may also be related to the city climatic zone.

Figure 1 shows the results of the five calibration synthesized in three categories: hot (which includes "slightly warm", "warm" and "hot"), comfort and cold (which includes "slightly cool", "cool" and "cold"). The common range of comfort for all calibrations was between 19 and 23°C. Above 31°C, all of them are categorized as hot. In Belo Horizonte[1] and Salvador, the limit for the cold category was not found. In the other researches, the superior limit for this category is 16 °C.

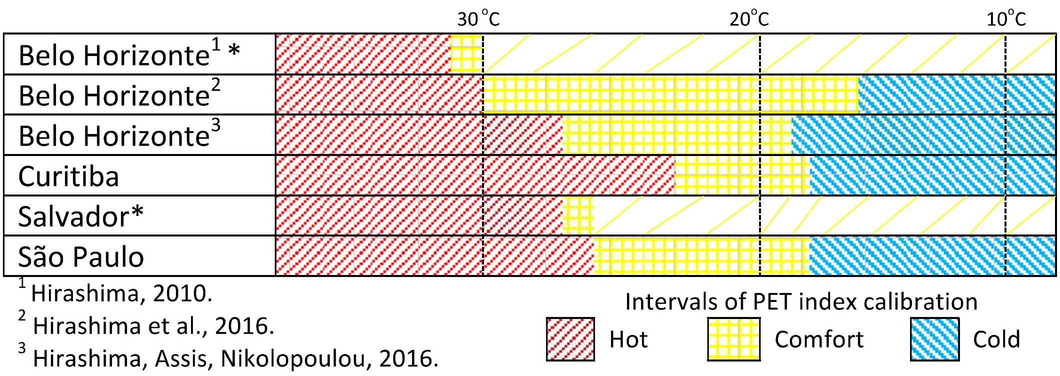

Figure 1. Synthesis of PET index calibrations in three intervals. In the calibrations marked with (*), the inferior limit of the comfort category was not determined.

Conclusion

This paper presented different methodologies used in Brazil in order to calibrate the PET index for the local population and their results for the cities of Belo Horizonte, Curitiba, Salvador e Sao Paulo. The results show that the methodologies used in the cited studies are effective and valid, presenting their singularities. Differences in climatic zones show differences in ranges of PET values that must be better investigated. The lack of information of some processes during the calibrations and the different methods used to do them make it difficult to compare the results.

This study can be configured as a guide that can conduce to an in-depth discussion, generating subsidies to future contributions in this field. The possibility of combining the presented methodologies represents an opportunity to explore and to enhance the study of the subject. However, this work also indicates that further studies should be carried out in order to evaluate the pertinence of using a symmetrical two-pole 3 or 5 point-scale in the assessment of the perception of thermal conditions in open urban spaces in Brazil, due to the tropical climate features, which is characterized by a small seasonal and diurnal variance in thermal conditions, presented in a large part of this country.

Considering the standardization of the calibration process, this work suggests that future studies should be carried out in order to define which specific methodological and statistical procedures should be used in the calibration of thermal indexes for urban spaces in Brazil, making it possible to compare thermal comfort zones in different cities, to predict thermal sensations of their population and to better assess their urban microclimates. We hope this will positively contribute to the suitable planning of open spaces in Brazilian cities, improving outdoor thermal conditions.

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