Thermal comfort comparison and evaluation in different climates

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Abstract

The growth of cities combined with an increased urban density leads to a considerable thermal stress and health risks. In this situation it is important to develop benchmarks of thermal comfort conditions, which can guide planners to a better urban design. The aim of this study is to present the results of investigations carried out in Belo Horizonte (Brazil, tropical climate), in Kassel and Freiburg (Germany, temperate climate). The same method was used in all cities in order to compare the limits of thermal stress and to study the response from the subjective evaluation of thermal sensation to the measured data. Microclimatic conditions were represented by the PET index. In each city, microclimatic data were measured simultaneously with the administration of questionnaires in all seasons, during 2009 and 2010, and in two squares (that noticeably differ in relation to their thermal environment and their morphological parameters, such as the sky view factor, the height of the buildings, the type of pavement, the presence of water sources and vegetation). The results show that neutral range in Brazil is from 16°C to 30°C PET and the hot range starts at 32°C PET. In Germany, neutral range is from 18°C to 28°C PET and hot range starts at 35°C PET. The very hot category starts in lower values of the PET index in Brazil (36°C) than in Germany (38°C). It seems that, in the evaluation of the thermal perception of the population for planning purposes, besides considering urban climate conditions of hot and cold weather, it is important to consider social and psychological aspects. In this study it was found that in colder climates people want to have some warm periods for short time, while in hotter climate people long for cooler conditions. The results pointed out that in colder climates some warm places should be kept in open spaces as long as they do not lead to heat storage. As expected, shadowing is an important design strategy in hot climates.

Keywords: thermal comfort, PET calibration, comparison among cities, urban structures.

1. Introduction

Thermal comfort and its effects on human beings are better understood through thermal indices consideration since air temperature is not an adequate indicator. There are several biometeorological indices available. In this study the Physiological Equivalent Temperature index (PET, Höppe 1999) was chosen due to different reasons: the first one is that it was adapted to outdoor settings; secondly it is internationally used which provides comparability. In addition to its wide use and distribution, it is furthermore continuously developed by several work groups.

PET is a physical index used to describe the thermal situation of a person including the meteorological parameters as Mean Radiant Temperature (Tmrt), Air Temperature (Ta), Wind Speed (v) and Relative Humidity (RH). It is defined as “the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed” (Höppe, 1999 page 73).

In studies of thermal comfort in urban areas, in addition to the meteorological (Tmrt, Ta, v and RH) and individual parameters (metabolic rate, thermal resistance of clothing, age, gender, etc.), social, cultural and psychological variables should also be considered.

Some studies agree that people with different cultures and adapted to different climates may react differently to the same thermal conditions, indicating that the thermal, emotional and perceptive evaluation of a physical place can be influenced by psychological processes based on sociocultural processes (Knez; Thorsson, 2006).

Rohles (1980 *apud* Höppe, 2002) found that in wintertime people tend to prefer warm to cold temperatures, while in summertime the opposite occurs. Available choice, environmental stimulation, thermal history, memory effect, expectations and so on also play an important role in the subjective evaluation of the microclimate conditions (Nikolopoulou; Baker; Steemers, 2001). The places' outer appearance influences thermal comfort as well as, for example, the people's attachment to them (Knez, 2005; Knez; Thorsson, 2006). Further studies show that a high variation of microclimates tends to be evaluated positively (Nikolopoulou; Baker; Steemers, 2001; Katzschner, 2006). So thermal perception does not only rely on the microclimate parameters but is also dependent on psychological issues. Therefore thermal comfort indices may not be applicable in different cultural/climate areas without adaptations if they do not consider psychological processes involved in the environmental evaluation (Knez; Thorsson, 2006).

Thermal conditions in urban areas are physically dependent on buildings settlement geometry, open space obstacles and surface materials (Katzschner, 2010; Assis et al., 2013), urban characteristics which may cause microclimates that can vary from very hot to cool.

Therefore, taking into account sociocultural, psychological and physical issues, variation of microclimates and the microclimate itself, guidelines should be found, including issues taken off all disciplines.

There are two dominant factors affecting thermal sensations in outdoor settings. One is mean radiation temperature and the other is wind speed. Especially higher wind speed seems to be negatively perceived by people living in moderate climates but positively perceived in warmer climates. Considering the predicted increase of temperature due to global climate change and findings from KLIMES Project (Mayer, 2008), wind is becoming more important in temperate climate regions and should be taken into account in further planning.

Considering the exposed above, this article intends to compare, in terms of physiological and psychological responses, thermal comfort of subjects of cities located in different climates and influenced by different cultures. The underlying hypothesis is that thermal comfort is differently perceived in different climates. Therefore, reaching the found limits for local thermal stress, which may not be the same all over the world, should be a justification for urban design strategies implementation in order to mitigate the impacts of climate extremes.

2. Objective

The aim of this study is to present a calibration of the PET index for cities located in different cultural/climate zones, and to compare the thermal comfort perception of subjects living in these cities within the same PET intervals.

3. Methods

The first stage of the methodology was to define the study areas. Belo Horizonte, in Brazil, and Kassel and Freiburg, in Germany, were chosen as cities that have no sea influence in continental climates, are located in valley climates, but have different levels in heat load.

Belo Horizonte (19°55'S, 43°56'W) is placed at the central portion of the state of Minas Gerais, located at the Southeastern region in Brazil. The city, which has about 2.375.151 inhabitants (IBGE, 2010) and an area of 331 km², is among the largest cities in Brazil. Considering the Köppen Climate Classification, the climate of Belo Horizonte can be classified as Aw, which corresponds to the wet tropical climate with average temperature of the coldest month above 18°C and distinct dry season in winter (Assis, 1990). Low velocity winds occur throughout the year (about 1.5 m/s) and the prevailing direction is east. In this study, two case areas were selected in the southeast of Belo Horizonte – *Liberdade* Square (Figure 1) and *Sete de Setembro* Square (Figure 2). Differences regarding the sky view factor (SVF), the height of buildings and the presence or not of water bodies and vegetation were considered as selection criteria. The contrasting areas should present different microclimatic conditions, which would contribute to obtain representative data of the amplitude that the range of the PET index could reach.

Fig. 1 - Liberdade Square and its SVF, Belo Horizonte. Photo: Hirashima, 2010.

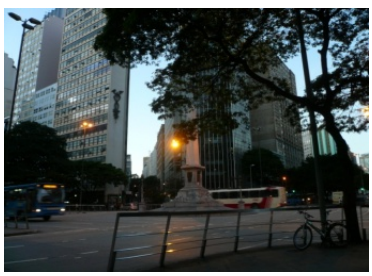

Fig. 2 - Sete de Setembro Square and its SVF, Belo Horizonte. Photo: Hirashima, 2010.

In Germany the cities of Freiburg and Kassel were chosen using the same criteria. Kassel is situated in the centre of Germany (51°17'N, 9°26'E) whereas Freiburg is in the south (47°59'N, 7°51'E). Considering the Köppen Climate Classification, the climate of Kassel and Freiburg can be classified as Cfb, meaning continental climate. Nevertheless Freiburg has significantly more sun hours than Kassel (8h and 6h respectively).

Freiburg Vauban (Figure 3) is a recently developed neighborhood with rich vegetation parts. The Opernplatz in Kassel (Figure 4) is an inner city open space with spare vegetation. In three sides it is surrounded by buildings and at the forth and open side is the main shopping street of Kassel.

Fig. 3 – Freiburg, Vauban District. Photo: Mayer, 2008

Fig. 4 – Opernplatz, Kassel. Photo: Kupski, 2009

The research design covers methods combining experimental investigations of microclimatic conditions and parallel interviews with people on site about their thermal perceptions in different climates.

The second stage of the methodology was to set a common questionnaire for Belo Horizonte (Brazil), Kassel and Freiburg (Germany), using as references the related international standards ISO 7730 (1995), ISO 9920 (1995), ISO 10551 (1995) and ISO 8996 (2004). Interviewees had to be acclimated adults between 20 and 59 years old, since this was estimated as the average population using outdoor spaces for the three cities. The questionnaire included individual and subjective variables. The individual variables were weight, height, age, gender, acclimation to the environment, physical activities and clothing. The subjective variable was perception of thermal sensation. The seven-point scale (ISO 10551, 1995) - *very hot, hot, warm, neutral, cool, cold and very cold* - was used after the question: "How are you feeling now?".

The surveys were conducted in all seasons (in each country) during 2009 to 2010 in order to obtain the wider PET range as possible. Microclimatic data were collected on sunny and shaded places in each survey area. The variables measured were air temperature, relative humidity, globe temperature (40mm-diameter gray globe - Thorsson et al. 2007) and wind speed, all of them at 1.10m (ISO 7726, 1998). Each interview was linked to the meteorological parameters measured at the point where the interview took place. The parameters were measured with a mobile meteorological station (Figures 5 and 6).

Fig. 5 - Assembling of instruments at the Belo Horizonte areas. Photo: Hirashima, 2010.

Fig. 6 - Assembling of instruments at the Kassel and Freiburg areas. Photo: Kupski, 2009

The collected data were used to calculate PET by means of the software developed by Holst (2007). The statistical analysis was performed using ordinal logistic regression (OLR). At this stage of the statistical analysis, graphs with seven curves referring to different categories of thermal sensation was generated for Belo Horizonte and for Kassel/Freiburg. At the point these curves intersect each other they mark the ranges corresponding to different thermal sensations, resulting in the calibration of the PET index for the local population.

4. Results and discussion

A total of 1182 questionnaires were considered valid in Belo Horizonte and 776 in Kassel and Freiburg. In Table 1, the averages of the PET values for the cities in Brazil and Germany can be seen. The averages show a

higher medium and maximum values for Kassel/Freiburg, but the minimum is equal. Otherwise thermal annual amplitude is wider in German cities.

Table 1 - Values of PET considering all data collected

City	PET (°C)			
	Max	Med	Min	Amplitude
Belo Horizonte	40	26	12	28
Kassel / Freiburg	54	28	12	42

In figures 7 and 8, the perception of thermal sensation for each range of PET values is presented. For generating these graphs, we regrouped thermal sensation scale in three categories: Hot (including the answers very hot, hot and warm), Neutral (including only the answer neutral) and Cold (including the answers cool, cold and very cold).

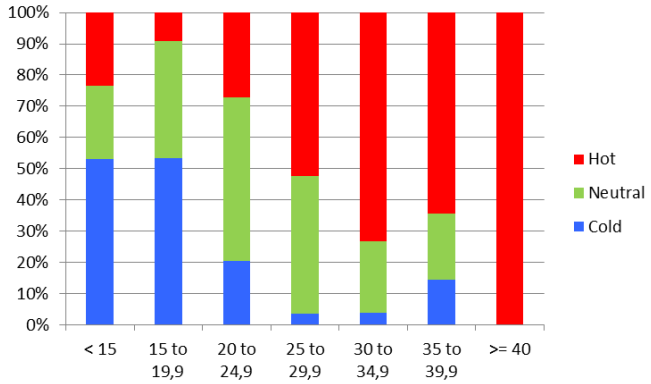

Fig. 7 - Graph of perception of thermal sensation for each range of PET values (°C) in Belo Horizonte (Brazil areas), after regrouping the perception scale in three points.

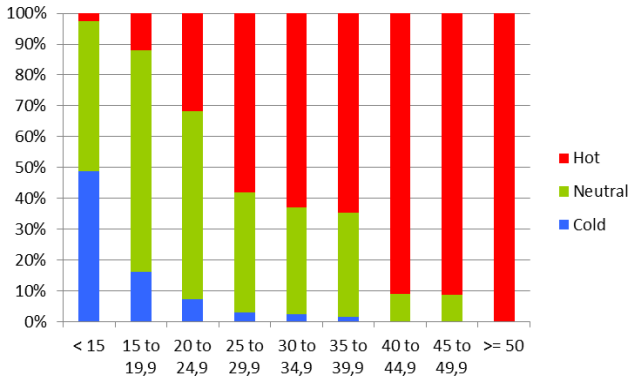

Fig. 8 - Graph of perception of thermal sensation for each range of PET values (°C) in Kassel and Freiburg (German areas), after regrouping the perception scale in three points.

Figures 7 and 8 show that, in the ranges of PET bellow 15°C and from 15°C to 20°C, the majority of people in the Brazilian city (more than 50%) perceives the climatic conditions as cold, while, in German cities, the majority of people perceives the climatic conditions as neutral. There seems to be a greater tolerance toward cold and lower PET values in Germany. In the 20-25°C PET range, the majority of people feel neutral in both countries´ cities. In the 25-30°C PET range, thermal perception of climatic conditions is quite similar in the Brazilian city and in German cities. For PET values over 25°C, the majority of people perceives the climatic conditions as hot in both countries´ cities. Over 30°C, the narrower range of people feeling neutral in the Brazilian city shows a low tolerance to hot weather in this country region. Over 40°C, 100% of people in Belo Horizonte feel hot, situation that happens only for PET values over 50°C in German cities. The greater tolerance to cold and hot conditions in Germany is possibly due to the wider annual thermal amplitude in this country.

Table 2 shows the results of the logistic ordinal regression, indicating the ranges corresponding to the different thermal sensations, resulting in the calibration of the PET index for the Brazilian and the German cities.

Table 2 - Summary table of PET intervals for Belo Horizonte and Kassel / Freiburg

Thermal Perception	**PET (°C)**	
	Belo Horizonte	**Kassel / Freiburg**
Very Cold	-	below 8
Cold	below 12	8 to 12
Cool	13 to 15	13 to 17
Neutral	16 to 30	18 to 28
Warm	31	29 to 34
Hot	32 to 35	35 to 38
Very Hot	over 36	over 38

The information provided in Table 2 shows that the “Very Cold” range could not be determined to Belo Horizonte, once thermal conditions do not reach very low PET values in this city. The upper limit of the “Cold” range is equal for Brazilian and German cities. The “Cool” range is narrower in Brazil, while the “Neutral” range is wider in the Brazilian city than in German cities. The “Warm” range could not be well determined to Belo

Horizonte. The “Hot” range has the same amplitude in all the cities, but the lower limit of this range starts at a lower PET value in the Brazilian city. The same happens to the “Very Hot” range, indicating that, as the temperatures start to rise, people tend to feel hot in Belo Horizonte open spaces.

Generally, to German cities, except for the “Neutral” range, which presents an amplitude of 10 degrees, the other ranges have a more constant amplitude of, approximately, 3 – 5 degrees. To the Brazilian city, the ranges “cool” and “warm” show narrower limits, indicating that Belo Horizonte inhabitants tend to be less tolerant to changes in the thermal conditions, probably due to the narrower annual climate amplitude. The wider “Neutral” range in Belo Horizonte (amplitude of 14°C), can also be explained by the narrower annual PET amplitude in this tropical region.

5. Conclusions

The response to thermal stress in cities in moderate and tropical climates can be quite different. According to the thermal adaptation and to a certain expectation regarding the thermal conditions, thermal comfort ranges change, once psychological and sociocultural processes play an important role in thermal comfort evaluation.

Differences in the calibration of PET for German and Brazilian cities show that sociocultural characteristics influence the evaluation of microclimate in urban areas. The PET neutral comfort value range in Belo Horizonte is from 16°C to 30°C PET and the hot range starts at 32°C, while in Kassel/Freiburg neutral range is from 18°C to 28°C PET and hot range starts with 35°C PET. A comparison of thermal perception in tropical and moderate climates shows differences in the comfort zone of approximately 4°C (PET). This means that a standard calibration of PET is not possible, but has to be matched the respective climate region.

An understanding of the sociocultural and psychological factors that influence the perception of thermal environments is essential for proper evaluation of comfort conditions and to make decisions in urban planning.

Urban planning and design need strategies and concepts in order to mitigate the impacts of urban heat load. These strategies have to consider urban climate conditions of hot and cold seasons, but also have to take into account that in colder climates people want to have warm periods for short time, while in hotter climate people long for cool. The thermal index PET showed lower values for the scale very hot in the Brazilian city than in German cities. We may suggest that, for open spaces design, in colder climates some warm places should be kept as long they do not lead to heat storage and for hot climates shadowing is important at any case.

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References

Assis, E. S., 1990: *Urban design strategies to mitigating the urban heat island: performance analysis of green areas in tropical climate*. Master Dissertation (in Portuguese), Rio de Janeiro: UFRJ.

Assis, E. S.; Sirqueira, C. A.; Bamberg, A. M., 2013: Influence of vegetation on urban microclimate through micrometeorological model simulation. In: XII ENCAC (Brazilian Meeting on Comfort in the Built-up Environment). *Proceedings*… (in Portuguese). Brasília: ANTAC/UnB, 10p. CD-ROM

Physiological Equivalent Temperature (calculation based on MEMI): *software*, 2007: version developed by HOLST, J. Freiburg: Albert-Ludwigs-Universität Freiburg.

Hirashima, S. Q. S., 2010: *Calibration of the physiological equivalent temperature index (PET) for open spaces in the city of Belo Horizonte, MG*. Master Dissertation (in Portuguese), Belo Horizonte: UFMG.

Höppe, P., 1999. The physiological equivalent temperature PET – a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, **43**, 71-75.

Instituto Brasileiro de Geografia e Estatística, 2010: *Contagem da População 2010*. Available at: <http://www.ibge.gov.br>.

International Organization for Standardization, 1998: *ISO 7726*: Ergonomics of the thermal environment - Instruments for measuring physical quantities. Genève.

____, 1995: *ISO 10551*: Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgment scales. Genève.

____, 2005: *ISO 7730*: Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Genève.

____, 2004: *ISO 8996*: Ergonomics of the thermal environment - Determination of metabolic rate. Genève.

____, 2007: *ISO 9920*: Ergonomics of the thermal environment - Estimation of thermal insulation and water vapour resistance of a clothing ensemble. Genève.

Katzschner, L. 2006: Microclimatic thermal comfort analysis in cities for urban planning and open space design. *Comfort and Energy Use in Buildings*, Network for Comfort and Energy use in Buildings (NCUB), London.

Katzschner, L., 2010: Thermal comfort evaluation for planning in cities under consideration of global climate change. *Forum Patrimônio*, **3**(2), 14p. Available at http://www.forumpatrimonio.com.br/seer/index.php/forum_patrimonio/article/view/39/34

Knez, I., Thorsson, S., 2006: Influences of culture and environmental attitude on thermal, emotional, and perceptual evaluations of a public square. *International Journal of Biometeorology*, **50**, 258-268.

Knez, I., 2005: Attachment and identity as related to a place and its perceived climate. *Journal of Environmental Psychology*, **25**, 207-218.

Mayer, H., 2008: KLIMES - a joint research project on human thermal comfort in cities. *Berichte des Meteorologischen Instituts der Albert-Ludwigs Universität Freiburg*, **17**, 101-117.
Nikolopoulou, M., Baker, N., Steemers, K., 2001: Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy*, **70**, 227-235.
Rohles, H., 1980. Temperature or temperament: a psychologist looks at thermal comfort. *ASHRAE Transactions*, **86** (1), 5-13, *apud* Höppe, P., 2002: Different aspects of assessing indoor and outdoor thermal comfort. *Energy and Buildings*, **34**, 661-665.
Thorsson, S. et al., 2007: Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology*. **27**, 1983-1993.