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Outdoor Comfort Study in Downtown Rio de Janeiro, Brazil

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1. Introduction

The main motivation of the present research is the definition of optimal thermal conditions for outdoor spaces in Rio de Janeiro. Such delineated “comfort zone for the outdoors” will be further important for future improvements in urban planning and landscaping proposals and thus influence the use of open spaces. Studies on thermal perception of local populations in outdoor spaces are crucial for a climate-responsive urban planning. A number of studies carried out in the field of outdoor thermal comfort is devoted to the proposition of design tools and guidelines for urban planning. From some of such studies, guidelines for improvement of outdoor spaces are proposed (Givoni 1998; Chrisomallidou et al. 2004; Katzschner 2005; Panogopoulos 2008; Ng 2009).

According to Koeppen-Geiger’s climate classification, Rio de Janeiro (22° 54' 10"S, 43° 12' 27"W) has a tropical climate with summer rains (Aw). Annual maximum temperature is on average 27°C and heat discomfort characterizes local climate throughout the year. Average maxima during summer are around 30°C. In such context, air-conditioning is a common strategy to reduce indoor heat –in this sample of 985 subjects only about 29% reported having no access to air-conditioning spaces during their everyday activities and at home.

2. Purpose

The purpose of this research is to understand thermal preferences and define a preliminary outdoor comfort range for the local population in downtown Rio de Janeiro. For that, the *Physiological Equivalent Temperature* Index - PET is used.

3. Method

The monitoring series were carried out along with the administration of standard comfort questionnaires throughout summer periods in 2012/2013 and 2013/2014. Summer conditions are in this case relevant as they characterize most of the climate type of Rio de Janeiro and present the most critical challenge to urban planners.

Fourteen monitoring campaigns took place at seven different monitoring points in pedestrian areas with limited vehicle access. The monitoring points were pre-defined for evaluation in respect of urban geometry attributes (narrow streets, proximity to green spaces and urban parks, uniform / non-uniform street canyons, public squares) and are located near historic sites of interest (Figure 1a). The definition of each point was based on photographic imagery of the surrounding area and on the obtained sky-view factor (SVF, obtained from fisheye images and calculated for each point).

For the measurements, a Davis Vantage Pro2 weather station, equipped with temperature and humidity sensors, anemometer cup with wind vane, silicon pyranometer and globe thermometer was employed, which was mounted on a bycicle (‘Meteobike’) for easy access to each point (Figure 1b).

The comfort questionnaire was aimed at the assessment of the respondents’ thermal perception, and was designed according to ISO 7730 symmetrical 7-point two-pole scales. Respondents were eventual passers-by, with a residency in Rio de Janeiro of no less than six months and which were exposed to the outdoors at least for 15 minutes.

a) b)

Fig. 1 Monitoring area (a) and “Meteobike” (b)

4. Results

The sample consists of 985 votes. The field work comprised fifteen campaigns, which were carried out on clear days within the time interval from 10 am to 3 pm. Measured air temperature ranged 25-37°C. Table 1 shows the dates and points covered during the summer campaigns. Thermal votes ranged from -1 to +3 in the 7-point assessment scale, with most of the thermal votes cast in the warm part (+1, +2, +3, corresponding to “a little warm”, “warm” and “hot”, respectively) which is consistent with the meteorological data for the period (Figure 2).

Tab. 1 Monitoring campaigns

Campaign	*Date*	*SVF*	*Monitoring Point*	*%*
1	16.10.2012	0,269	Point 3	13
2	23.10.2012	0,287	Point 2	6
3	29.10.2012	0,269	Point 3	5
4	19.12.2012	0,111	Point 5	5
5	24.12.2012	0,252	Point 6	4
6	15.01.2013	0,454	Point 4	4
7	18.12.2013	0,111	Point 5	8
8	20.12.2013	0,287	Point 2	11
9	21.12.2013	0,269	Point 3	8
10	07.01.2014	0,252	Point 6	5
11	18.12.2014	0,36	Point 6	6
12	07.01.2015	0,272	Point 1	7
13	08.01.2015	0,454	Point 4	7
14	09.01.2015	0,269	Point 3	5
15	12.01.2015	0,287	Point 2	6

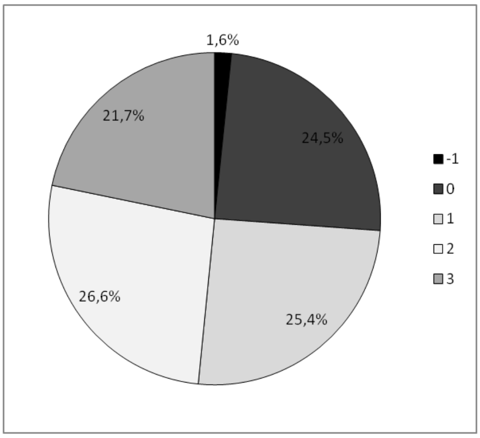


Fig. 2 Thermal sensation vote distribution

The outdoor Physiological Equivalent Temperature (PET) index (Mayer and Höppe 1987) was used for comparisons with the field data (thermal sensation votes). The PET index, expressed in °C, is defined by Höppe (1999) as the equivalent temperature to the air temperature in which, for a typical internal situation, the thermal balance of the human does not change, considering the same core and skin temperatures as in the original situation. RayMan Pro (Matzarakis et al. 2007, Matzarakis et al. 2010) was used for PET calculations.

The input parameters for assessing PET were: location, time of day and year, air temperature, humidity, wind speed, and the mean radiant temperature. The personal input variables were assumed to be that of an average man or woman[1] (matching the respondent, with his/her corresponding clothing insulation) with a metabolic rate of 2.3 Met, in agreement with the survey assumptions (ISO 8996). Figure 3 shows two sets of data: thermal sensation votes as a whole versus calculated PET and binned data for both, averaged for every 1°C in the PET scale.

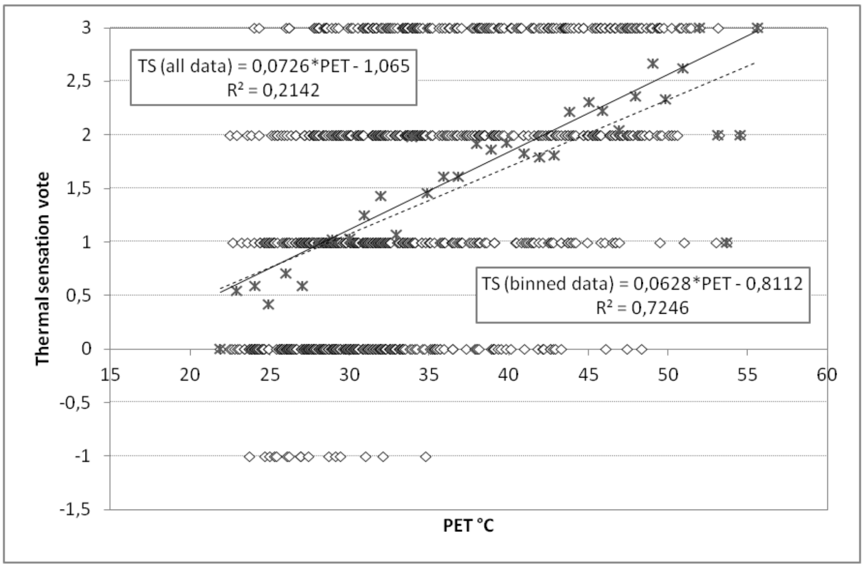
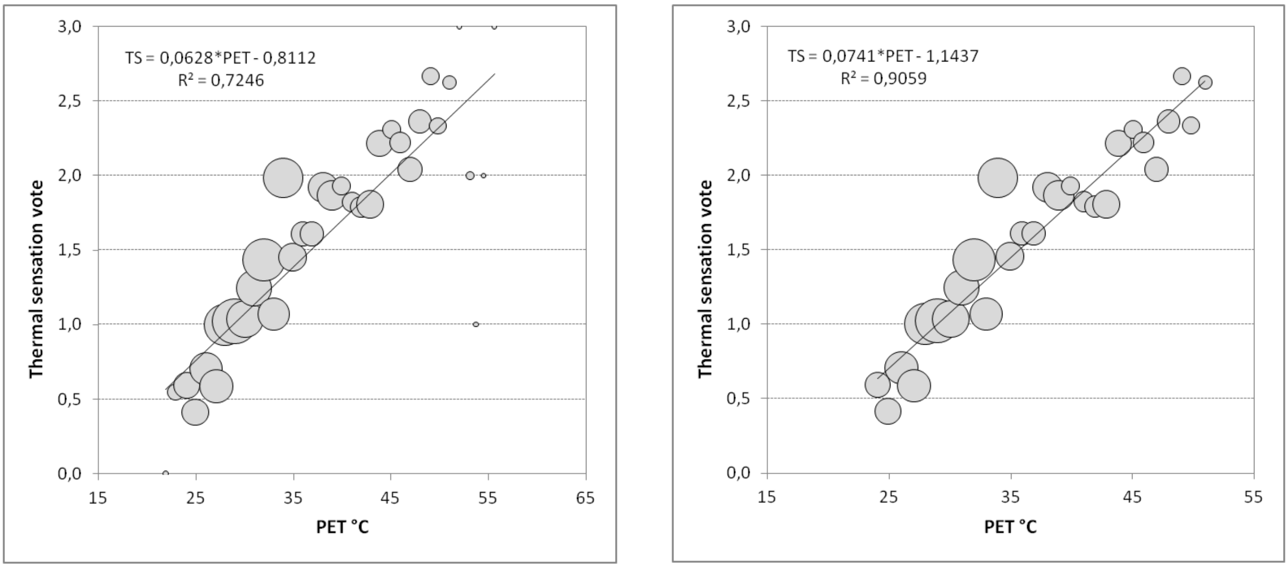


Fig. 3 Thermal sensation vote versus PET (all data and for binned PET values for 1°C PET scale)

Correlation between the thermal sensation and PET (bins of 1°C PET scale) is high, but the derived neutral temperature (for TS=0) is around 13°C in the PET Scale, which is very low. The comfort sensation assessment ranges for PET (Jendritzky et al. 1990; Matzarakis and Mayer 1997) suggest 8-13°C PET as giving a "cool" sensation with "moderate cold stress" as the corresponding grade of physiological stress. Our data set is for passers-by with an estimated metabolic rate of 2.3Met and with a clothing insulation level ranging 0.2-0.7 clo, thus the very low neutral temperature in the PET scale would not be expected. The number of respondents for each bin in the PET scale varied as shown in the bubble graph (Figure 4). Disregarding the bins with n<5 respondents as outliers, correlation increases and the regression curve yields a neutral temperature somewhat higher (15,4°C PET), which is still on the cooler side, "slightly cool" sensation with "slight cold stress" as the corresponding grade of physiological stress.

[1] According to ISO 8996, an average man is 30 years old, weighs 70 kg and is 1.75 m tall; the average woman is 30 years old, weighs 60 kg and is 1.70 m tall.



a) *b)*

Fig. 4 Thermal sensation vote versus PET (binned PET values for 1°C PET scale), bubble graphs for all bins (a) and with more evenly distributed bins (b)

Since 29% of the sample reported using air-conditioned spaces around the time of the interview, the low neutral temperature could be due to acclimatization and thermal expectation effects of such respondents towards cooler environments, therefore giving us lower than expected neutral temperatures. A breakdown of the data set into three categories gives us a diversified picture of such effect in terms of thermal perception (Table 2). Significant differences were found for respondents who reported no access to air-conditioning relative to the group with prolonged usage of air-conditioning. Even though “n” varies for each sample group (it should be stressed this is not an experimental study *per se*), there is a rise in reported TS with an equivalent drop in TP for AC-users. Such changes are noticeable for AC-usage at home, which could be linked to socio-economic aspects of the respondents.

Tab. 2 Grouped thermal sensation and preference votes vis-à-vis air-conditioning use

	No use of AC	***AC use at home or at work***	***AC use only at home***	***AC use only at work***	***AC use at home AND at work***
n	*282*	*387*	*164*	*223*	*316*
Thermal Sensation (TS)	1,2	1,4	1,6	1,3	1,6
Thermal Preference (TP)	-0,7	-0,8	-0,9	-0,7	-0,9
Differences TS	-	*0,2*	*0,3*	*0,1**	*0,4*
Differences TP	-	*-0,1**	*-0,2*	*0,0**	*-0,3*

**Non significant differences for a 95% level of confidence*

Thermal comfort impacts of urban morphology

Table 3 gives the variation in thermal perception for the range of urban morphology attributes covered, expressed by the sky-view factor (SVF) assessed at each monitoring point. As the first point is less representative in terms of number of respondents, comparisons should be drawn for the other situations. Obtained data does not suggest a strong relationship between reported thermal sensation/preference (both averaged for each group) and local SVF. A more detailed analysis would be necessary taking into account other relevant urban morphology attributes. Another complicating issue: since the points were measured on different dates, a direct comparison is not possible.

5. Discussion and conclusions

Cândido et al. (2010) use the term “addiction” for long-term AC users who exhibit a diminished tolerance for a greater variability in thermal conditions such as in naturally ventilated spaces. The field study conducted by those authors showed that for indoor environments (naturally ventilated classrooms) the thermal history of AC-users played an important role in their reported thermal perception, shifting TS towards heat stress for occupants with prior exposure to AC in their workplace. Chun et al. (2008) showed from a study in a climate chamber aimed at the understanding of the impact of thermal history on reported TS slightly higher TS votes for respondents who had been previously exposed to air-conditioned spaces.

Tab. 3 Grouped thermal sensation and preference votes vis-à-vis sky-view factor

SVF	***TS avg***	***TP avg***	***PET range***	***n***
0,038	0,5	-0,6	21,9-28,8	*31*
0,111	1,3	-0,7	23,2-44,6	*112*
0,252	1,8	-0,9	22,4-46,7	*156*
0,269	1,3	-0,7	22,5-52,2	*213*
0,272	1,5	-0,9	25,3-51,1	*134*
0,287	1,3	-0,9	26,3-43,7	*178*
0,454	1,6	-0,9	26,0-55,7	*161*

Thus, AC-usage may have an effect on observed thermal sensation of the passers-by, confounding the relationship between microclimatic conditions and overall thermal response.

Morphology attributes were expected to have an effect on perceived thermal sensation however no noticeable changes were verified. Future analyses should address this issue, e.g. by using binned data and other urban form factors (area ratio with vegetation, proximity to the coast among other factors).

Acknowledgements

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