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Identifying potential effects from anthropometric variables on outdoor thermal comfort

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ABSTRACT

In this study, we carried out outdoor thermal comfort surveys with pedestrians during warm periods of the year throughout 2012 to 2015 in downtown Rio de Janeiro, Brazil. Monitoring points were defined in respect of urban geometry attributes. For the measurements, a light-weight weather station was used, to which a gray globe thermometer was attached. The 'Universal Thermal Climate Index' (UTCI) and the derived 'Dynamic Thermal Sensation' (DTS) units were used as baseline for comparisons with reported thermal sensation votes from 985 respondents. The survey questionnaire included questions as regards thermal perception as well as personal, self-reported characteristics of the respondents. We analyze results in terms of influencing aspects on reported thermal sensation due to anthropometric characteristics of the sample, including gender, age, body mass and skin colour. Results point to the statistical significance of body mass as well as skin colour in moderating the effect of thermal conditions on users' thermal judgement. Gender effects were found to be insignificant whereas age impacts can be a matter of concern in climate-sensitive urban design. In the multivariate regression equation obtained from raw data, along with the meteorological data only skin colour was found to be a good predictor, slightly improving its predictive power.

1. Introduction

The development of outdoor comfort research in Rio de Janeiro, Brazil, is of particular importance, since users of open spaces are exposed to heat stress during most part of the year. The city recently attracted international attention during the Olympic Games 2016, which involved heavy investments in infrastructure including urban mobility innovations and the regeneration of a degraded waterfront area. Meeting thermal expectations of pedestrians with adequate urban design strategies could further enhance the quality of life in the downtown area, serving as significant guidance in upcoming urban projects and interventions.

In the context of climate-sensitive urban planning, there is a great need for defining urban design strategies which could be adequate to the needs of users of outdoor spaces [1]. However, in respect of thermal perception assessment of urbanites, subjective factors may confound a clear definition of what should be considered adequate from a thermal comfort point of view.

Among the driving factors behind thermal sensation, anthropometric differences can respond to a certain extent to the subjectivity factors behind reported thermal sensation votes. Tuomaala et al. [2] discuss the rationale behind a more holistic approach of thermal sensation, whereby external, environment-driven factors and internal, subject-related aspects participate in the perceived thermal sensation. In respect of subject-related, anthropometric characteristics of the surveyed population, a few relevant studies can be found in the literature. In most cases, the analysis is carried out by grouping different sets of interviewees according to a given anthropometric feature.

Karyono [3] carried out a field study with 596 office workers in Indonesia with questionnaire surveys and concurrent onsite monitoring. Results were interpreted in terms of the neutral temperatures achieved by different subgroups according to gender, age and body mass effects. Overall, men felt warmer than females did, yet differences were rather negligible and statistically insignificant at 5% level. As regards age differences, older people showed slightly lower neutral temperatures than young subjects did. As for 'Body Mass Index' (BMI), Karyono [3] found that subjects with higher body mass tended to have lower neutral temperatures than those with normal body mass (20–25 kg/m^2).

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Karjalainen [4] carried out controlled experiments with over 3000 subjects in what the author termed “everyday thermal environments” with the purpose of assessing their thermal responses with respect to gender differences. Results obtained both for offices and homes indicated that women tended more frequently to feel uncomfortably hot than men. Such findings conform to a description of a laboratory study [5] with a limited sample of 16 young females and 16 young males under thermally controlled conditions and with standardized clothing insulation. Although gender differences were rather small and considered as not having practical implications, for warm indoor conditions, females reported feeling hotter than male subjects did.

In a climate chamber-based investigation of gender effects on thermophysiology, thermal comfort and productivity with 10 young females and 10 young males, Schellen et al. [6] found that female subjects felt less comfortable and more dissatisfied compared to male counterparts. Apart from thermal differences due to physiological causes, subjective responses to the same comfortable thermal conditions indicated that females reported slightly cooler thermal sensation votes than male subjects. Another lab-based study with nine young female and nine young male subjects, evaluated gender-related differences with Chinese participants and concluded that there were no significant inter-gender differences in terms of thermal sensation when near neutral thermal conditions [7].

For the hot conditions of Hyderabad, India, Indraganti & Rao [8] looked at gender and age effects on reported thermal comfort in residential, naturally ventilated buildings. From 100 subjects surveyed in a longitudinal study, only small differences were found between men and women in terms of thermal sensation votes, with the latter feeling in general more comfortable than men under hot thermal conditions. A subsequent study [9] with a substantially larger sample (2787 occupants in 28 office buildings in India) showed more noticeable gender differences, however such differences varied according to the operation mode of the building surveyed. In naturally ventilated buildings, comfort temperature differences were found to be significant whereas in air-conditioned buildings such differences did not reach statistical significance. Overall, women preferred higher temperatures.

Choi et al. [10] carried out a user-satisfaction survey in office buildings in the U.S. with just over 400 subjects who at the time were at their workstations. Results found that during the cooling season women tended to feel more dissatisfied with their thermal environment than men did, with statistical significance.

As for age effects on perceived thermal sensation, Indraganti & Rao [8] found that older people in general have a slightly lower thermal sensation than younger subjects, when comparing two subgroups (<40 years old and $\geq$40 years old). Such effect is suggested by the authors to result from lower metabolic rates and due to a more sedentary life style of the elderly [11]. Older subjects also showed higher satisfaction levels with higher percentage of “no change” thermal preference votes. In a subsequent study, Indraganti et al. [9], upon splitting their sample of 2787 office workers into two groups (below and above 25 years old) confirmed those findings and showed that comfort temperatures were higher for the younger group and that such differences remained even when gender aspects were taken into account.

Temperature sensitivity decreases with age. In a climate chamber-based study on the effect of a moderate temperature drift on thermal comfort of eight young adults and eight older subjects, Schellen et al. [11] found out that the reported thermal sensation of the elderly was, in general, lower in comparison with that of younger participants.

Taylor et al. [12] analyzed differences related to age differences in respect of the ability of subjects to regulate room temperature. Two groups of healthy males with age differences were able to change room temperature in a comfort chamber, adjusting it when air temperature moved outside their preferred range. Subjective ratings of thermal sensation, discomfort, and affect were provided at each change in temperature settings. During heat-induced changes, the elderly subgroup felt more comfortable than the younger counterparts did. Authors concluded that elderly people may require a more intense thermal stimulus to elicit the appropriate behavioural responses in the home and this fact could be further linked to more frequent dysthermia incidences in older people. Another study [13] using the same approach (room temperature control with two age groups) suggested that physiological and behavioural changes both contribute to the increased vulnerability of old people: the elderly preferred the same mean comfort temperature but manipulated ambient temperature much less precisely than the young.

Indraganti et al. [9] showed that subjects with low BMI (assumed as lower than 18.5Kg/m^2) reached higher comfort temperatures than the ones with high BMI (assumed BMI > 25 kg/m^2). In a simulation-based study, Tuomaala et al. [2] used a transient, multi-nodal Human Thermal Model (HTM) to predict human thermal comfort when taking into account individual characteristics such as gender, age and BMI. Using fixed environmental parameters for a test room, and assuming constant clothing levels, metabolic rate and height, age and BMI were varied for the two genders. Main findings showed that: increases in age showed decreases in thermal sensation, lower thermal sensation was found for females and, in general, BMI had a minor impact on thermal sensation data. In the latter case, increasing BMI was found to decrease slightly the thermal sensation index used in the predictions.

Andersen e Maibach [14] state that research focused on racial or skin colour distinctions among individuals remain scarce due to the risk of triggering racial prejudice. There is also an inherent difficulty of controlling for socioeconomic and cultural factors behind the ethnicity of the surveyed population. With the aim or understanding the effect of individual aspects behind the thermal perception in a questionnaire-based survey in Melbourne, Australia, Shooshtarian & Ridley [15] carried out a field study in the premises of a university campus. Authors used the Physiological Equivalent Temperature ‘PET’ index [16] as baseline for comparisons between reported thermal sensation of different subgroups. Results from binned data for 1 °C PET intervals suggested that respondents with darker skin colour had increased sensitivity to heat stress conditions.

Pantavou et al. [17] used the outdoor Universal Climate Index ‘UTCI’ in questionnaire surveys in Athens, for evaluating whether subjective factors of the surveyed population were well captured by the index values. Higher thermal sensation votes were found for the female subgroup. With regard to age, a decreasing percentage of votes in heat stress was noticed for increasing age classes. A similar behaviour as regards gender was observed in another questionnaire survey in outdoor environments [18] where Taiwanese females showed diminished tolerance to heat under hot humid conditions. In that study, such trend was explained in part by behavioural and cultural attitudes towards having lighter skin tones and preference for shaded areas.

The present paper explores the individual effect of anthropometric variables (gender, age, body-mass and skin colour) on reported thermal sensation. The contribution of the paper is to assess and understand the relative importance of such variables when defining optimal thermal conditions for pedestrians. From a clear understanding of the extent of anthropometric variables on thermal perception, it will be possible to set priorities in climate-responsive urban design. The issue discussed is aligned with the