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OUTDOOR COMFORT STUDY IN CURITIBA, BRAZIL: EFFECTS OF GENDER, BODY WEIGHT AND AGE ON THE THERMAL PREFERENCE

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ABSTRACT

The purpose of this article is to present results of an outdoor comfort research in the main pedestrian street of Curitiba, Brazil (25º31'S, 917m elevation). Urban locations have been monitored regarding standard comfort variables: air temperature and humidity, wind speed and globe temperature. Alongside the quantitative assessment of comfort conditions, a survey of pedestrian's thermal comfort perception according to ISO 10551 was carried out on each monitoring campaign by means of questionnaires with the local population. As a whole, from fourteen monitoring campaigns using a couple of weather stations, beginning on January 9 through August 12, over 2000 valid comfort votes were obtained. In this paper, we present the analysis of observed thermal sensation with regard to gender, body weight and age differences, concerning the sensitivity of different groups to heat and cold.

Keywords: comfort in open spaces, thermal comfort, urban climate.

1. INTRODUCTION

As a consequence of global warming, several impacts have been observed in human populations worldwide over the last decade. The most severe events related to climate change occurred in the years of 1998 (the hottest year registered by the World Meteorological Organization), 2002 (the second hottest) and 2003. According to Roaf, Crichton and Nicols (2005) the most dramatic summer season for Europeans was during the months of June-August 2003, when monthly average temperatures were about 5 degrees higher than the average of all other months of that year. Several deaths were related to climate change during that summer season, with totals around 300 thousand people in some European countries, including Great Britain.

Aside from extreme climatic events such as hurricanes, floods and fires, which can be responsible for losses or damages of insured real states (Munich Re reported 75% of losses in 2003 as a consequence natural catastrophes due to climate change – www.munichre.com), global warming will have an impact on cities. Especially coastal cities are more subject to natural disasters.

From the thermal comfort point of view, some of such impacts are indirectly linked to the increased need of air conditioning systems in buildings located in hot regions (or in regions with hot summer season) in order to ensure comfort conditions for their occupants. Consequences of an increased usage of air-conditioners are associated to a corresponding increase of electric energy demand. More directly, global warming will interfere with the microclimatic conditions one is exposed to in urban areas, when working or staying outdoors.

A large part of urban growth takes place in sub-tropical latitudes. Urbanization in these areas has led to both densification and urban sprawl, and these major land use changes – which are often unplanned – can have significant environmental consequences. Urban climate, which is influenced by land use patterns, heat-generating activities, and the physical texture of urban construction, has a great impact on outdoor comfort as well as on a building's energy consumption. A climate-responsive urban planning can provide optimal, comfortable thermal conditions not only for the permanence of humans in outdoor spaces but also reducing the need of air conditioning systems in buildings.

Recognizing that modifications in the physical attributes of the urban space are able to promote improved thermal conditions in the outdoor and thus positively influence the use of open spaces, two specific objectives were proposed for the research initiative funded by the Brazilian National Council of Technological and Scientific Development (CNPq):

1) to define optimal thermal comfort ranges for passers-by in pedestrian streets, from field studies conducted in Curitiba, Brazil

2) to recommend urban design strategies and guidelines for the improvement of outdoor comfort in such location

The present paper is concerned with the first objective and aims to evaluate the effect of gender, body weight and age differences on the perceived thermal sensation from an extensive series of measurements and comfort surveys with local population.

2. RESEARCH AREA

Curitiba, a city of 2 million inhabitants in southern Brazil, has a long history of urban planning, which started in the 1930s. Later, with an ever-increasing urban growth, the city plan underwent a series of revisions of the Master Plan which led to an innovative mass transportation system capable of supplying current and future demands, as well as measures for preserving the city's heritage and green areas. This planning process, which has attracted worldwide attention as a model of sustainable urban development (Hawken et al. 2003), is based on the principle that land use in the city can be induced, restricted, and organized. Considering the long history of the city's urban planning and the importance of sustainability considerations in this process, it is considered essential to develop innovative tools for urban climate analysis which could have an application in Curitiba's future growth.

Concerning the climate of Curitiba (25º31'S, 917m elevation), average temperatures in summer range between 17 and 20 ºC and in winter between 12 and 14 ºC (Goulart et al. 1998). Annual average temperature is about 16ºC. Daily amplitudes may vary between 0.5 and 25.7 ºC, and the average swing is 10.5 ºC. Absolute humidity ranges between about 4 to 18 $g.kg^{-1}$, with an average of about 11 $g.kg^{-1}$. Annual precipitation is around 1600mm.

3. METHOD

Measurements were taken between January and August 2009, over a wide range of air temperatures, wind conditions and solar angles and height.

Monitored climatic variables are according to ISO 7726 (1998). Measurements were carried out at two points each day, spanning up to five hours (typically from 10am to 3pm local time). Two HOBO Onset weather stations were used (Figure 1), equipped with a three cup anemometer (at approximately 2.1m height), air temperature and relative humidity sensors at 2.1, two Copper gray-colored globe thermometers (for measuring globe temperatures at two heights) and a silicon pyranometer at 1.6m. Data from all sensors were recorded every five seconds, and averaged over one minute.

Figure 1: Microclimatic measurements

The Mean Radiant Temperature (MRT) was obtained from measurements with globe thermometers two inches in diameter and painted with RAL-7001 (gray) (Thorsson et al. 2007). Two heights were considered, 0.6 m and 1.1 m, according to ISO 7726 (1998). For the calculation of the MRT the average of both measurements was used.

Accuracy ranges of the used equipment are in agreement with the recommendations of ISO 7726 (Table 1). However, it should be reminded that ISO 7726 applies to two kinds of environments, none of them referring to outdoor conditions.

Personal data were based on answers to a thermal comfort questionnaire, designed from recommendations of ISO 10551 (1995). The first part of the questionnaire consists of questions related to gender, age, height, weight, clothing, time of residency in Curitiba (to account for acclimatization, considering a minimum time of six months) and time spent outdoors, and the second part deals with questions related to thermal perception and preference. The five scales described in ISO 10551 encompass five kinds of judgment: perceptual, affective evaluation, thermal preference, personal acceptability and personal tolerance. In the present paper, we analyze results concerning:

- thermal perception (perceptual scale): “How do you feel at this exact moment?” – we used in this case the symmetrical 7-degree two-pole scale (very cold=-3 to very hot=+3)
- thermal preference: “At this exact moment, I would prefer to be …” – again, we used the symmetrical 7-degree two-pole scale (much cooler=-3 to much warmer=+3)

Table 1: Recommended accuracy versus sensors’ accuracy

Quantity	Required measurement range (comfort)	Required accuracy (comfort)	Measurement range/HOBO Onset sensor used	Accuracy
Ambient temperature (Ta)	10 - 40ºC	Required: ± 0.5ºC Desirable: ± 0.2ºC	-40 - 75ºC (S-THB-M002)	0.2ºC
Mean Radiant Temperature (MRT)	10 - 40ºC	Required: ± 2ºC Desirable: ± 0.2ºC	-40 - 70ºC (U23-004) -40 - 100ºC (S-TMB-M002)	0.2ºC
Air velocity (va)	0.05 - 1 m/s	Required: ± (0.05 + 0.05va) m/s Desirable: ± (0.02 + 0.07va) m/s	0 - 44 m/s (S-WCA-M003)	± 0,5 m/s
Absolute humidity expressed as partial pressure of water vapor (pa)	0.5 – 3.0 kPa	± 0.15 kPa	0 - 38.7 kPa (S-THB-M002)	within the range

4. RESULTS

4.1 Obtained data and characterization

As a whole, from fourteen monitoring campaigns, beginning on January 9 through August 12, 2024 valid comfort votes were obtained. Votes considered ‘valid’ were the ones where thermal perception and thermal preference had not the same values, either positive or negative: e.g. “feeling warm” (+2) versus “I would prefer to be much warmer” (+3). In addition, respondents who reported having some kind of illness (cold, cardiovascular problems, physical disabilities etc) by the time of the interview were not considered.

The obtained sample consists of 57% male and 43% female respondents, with ages ranging from 13 to 91 years old. Ambient temperatures measured during the 10am-3pm intervals ranged between 6.4-30.7 ºC, with corresponding relative humidities 23-93 %, while the mean radiant temperature varied within the range of 8.2-46.5 ºC. Obtained temperatures are evenly distributed, with 52% above and 48% below the average of 20.3 ºC.

The comparison between thermal perception votes against thermal preference is shown in Figure 2.

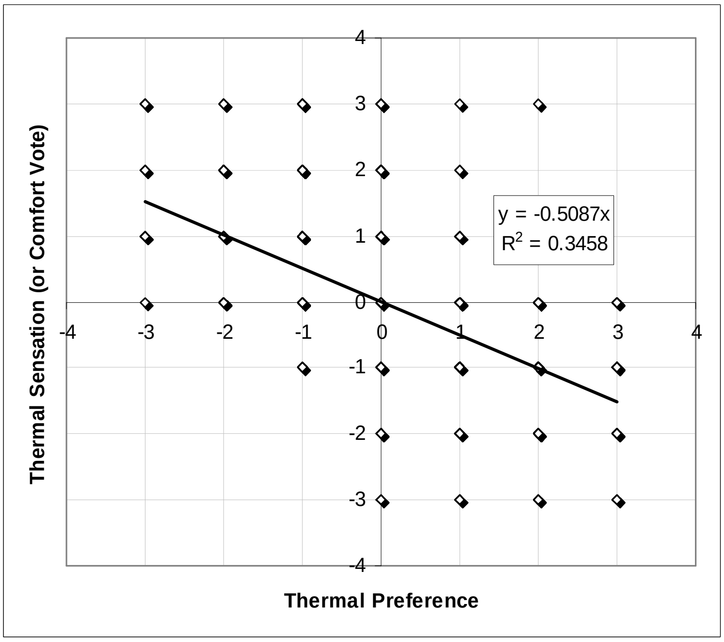

Figure 2: Thermal sensation versus thermal preference

The graph shows the expected relationship between both variables. Although there is a great dispersion in the graph, correlation (R = 0.59) is significant. The distribution of declared sensation and preference votes is shown in a histogram (Figure 3). A consistency is found in the data, with about 40% of the respondents feeling comfortable.

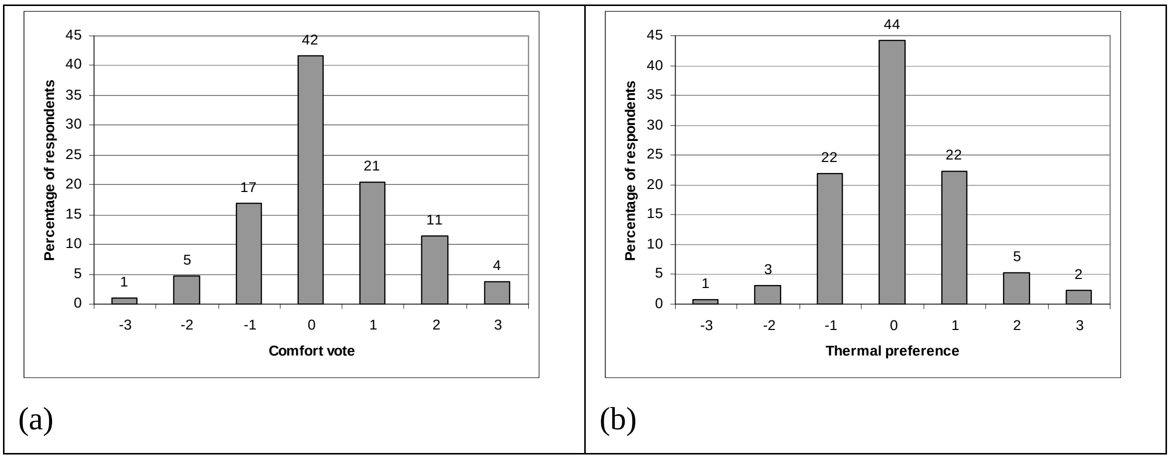

Figure 3: Thermal sensation (a) versus thermal preference (b) histograms

4.2 Expressing thermal sensation as a function of microclimatic factors

The first issue in generating a formula expressing the measured thermal sensation (TS) as a function of the climatic conditions to which the surveyed people were exposed was the choice of the input variables, out of the list of measured climatic factors.

The measured climatic factors, as mentioned above, were: air temperature (Ta, given in ºC), wind speed (WS, given in m/s), relative humidity (RH, given in %), solar radiation (SR, given in W/m²) and globe temperature (GT, given in ºC). From the combination of the air and globe temperatures, the MRT (given in ºC) was calculated.

The Choice of the Humidity Factor

Ambient humidity usually is measured in terms of relative humidity, mainly because of availability of simple and inexpensive instruments for measuring it. However, from the human physiology aspect, the relative humidity is not the determining factor as the evaporation from the lungs and sweat evaporation from the skin surface depend on the difference in absolute humidity, or the humidity ratio (HR, in g/kg). The lungs' temperature is practically constant and the range of the average skin temperature under a wide range of air temperature, except under very cold conditions, is very small. Ambient air in contact with the skin has a temperature very close to it. Consequently, HR is more appropriate in evaluating the physiological effect of humidity.

The calculation procedure of the humidity ratio from the measured air temperature and relative humidity takes into account standard ASHRAE psychrometric relations for air pressure corresponding to the 917m elevation of Curitiba.

The Choice of the Input Variables

The procedure of the choice of the input variables was to start with air temperature (Ta), wind speed (WS) and solar radiation (SR), and to see the correlation coefficient (CC) between the measured and the computed thermal sensations by that formula. Then, the MRT and/or the humidity ratio were added to the input variables, and the resulting CC values were compared, also taking into account the ease of assessing and general availability of such data in standard meteorological stations.

Thus, 4 successive formulas were generated:

TS1 = -2.26+0.1293*Ta-0.2744*WS+0.0007*SR; CC=0.6647 (Eq.1)

TS2 = -2.26+0.1267*Ta-0.2759*WS+0.0007*SR+0.0059*HR; CC=0.6647 (Eq.2)

TS3 = -2.26+0.1226*Ta-0.2617*WS+0.0005*SR+0.0162*MRT; CC=0.6664 (Eq.3)

TS4 = -2.26+0.1026*Ta-0.2642*WS+0.0004*SR+ 0.0173HR+0.01286*MRT; CC=0.6662 (Eq.4)

The differences in the CC values between the different formulas were very small. Humidity ratios are not often calculated and globe temperatures and MRT also are often unavailable. Consequently, the first formula was used in the analysis of the data.

The analysis included the following topics:

- Gender differences in sensitivity to heat and cold;
- Age effect in sensitivity of male and female subjects to heat and cold;
- Body weight effect on total surveyed population.

Gender differences in sensitivity to heat and cold

The combined effect of air temperature, wind speed and solar radiation is expressed in TS1 (Eq.1). Its range represents the range from the coolest to the warmest exposure of the surveyed people.

Expressing the measured thermal sensation of the surveyed male and female subjects as a function of the computed TS on the same graph can show their relative sensitivity to heat and cold, as seen in figure 4.

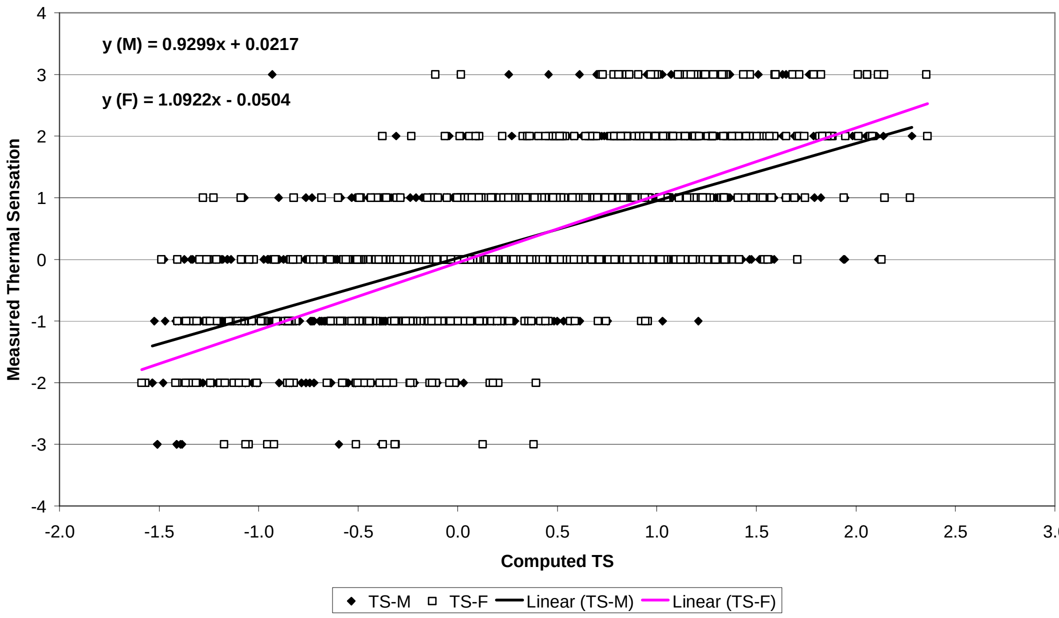

Figure 4: Gender differences in sensitivity to heat and cold

In can be seen in figure 4 that under comfortable conditions, around TS=0, the responses of men and women were about the same. However, under the coolest conditions women have felt the conditions a little more uncomfortably cold than men, and under the warmest conditions women have felt it a little more uncomfortably hot. This suggests a somewhat higher sensitivity of female subjects to uncomfortable conditions.

Age effect in sensitivity of male and female subjects to heat and cold

The range of ages of the surveyed people was very large: from 13 to 91 years.

In order to see the age effect on the sensitivity to heat and cold the total population of surveyed people, 1144 male and 880 female subjects, was divided into 4 age groups. Concerning the chosen age intervals, we had the clearest effect with the following age intervals: 14-24, 25-39, 40-59, 60-90.

Male subjects

Figure 5 shows the measured thermal sensations of the 4 age intervals of male subjects as a function of the computed thermal sensation. Under cold conditions there were very small differences between the different age groups but under heat conditions there was a clear pattern of age effect: as the males group was younger, it was more sensitive to heat.

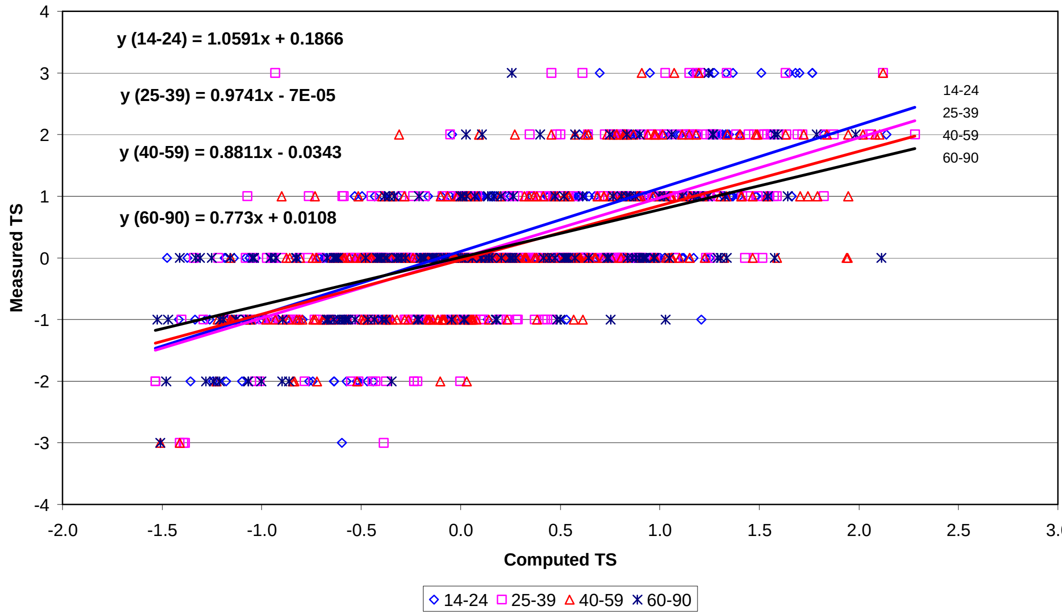

Figure 5: Age effect on sensitivity of male subjects to heat and cold

<u>Female subjects</u>

Figure 6 shows the measured thermal sensations of the 4 age intervals of female subjects, as a function of the computed thermal sensation.

It can be seen that with female subjects we had a similar pattern as with male subjects, but with even larger differences between the different age groups: as the females group was younger, it was more sensitive to heat.

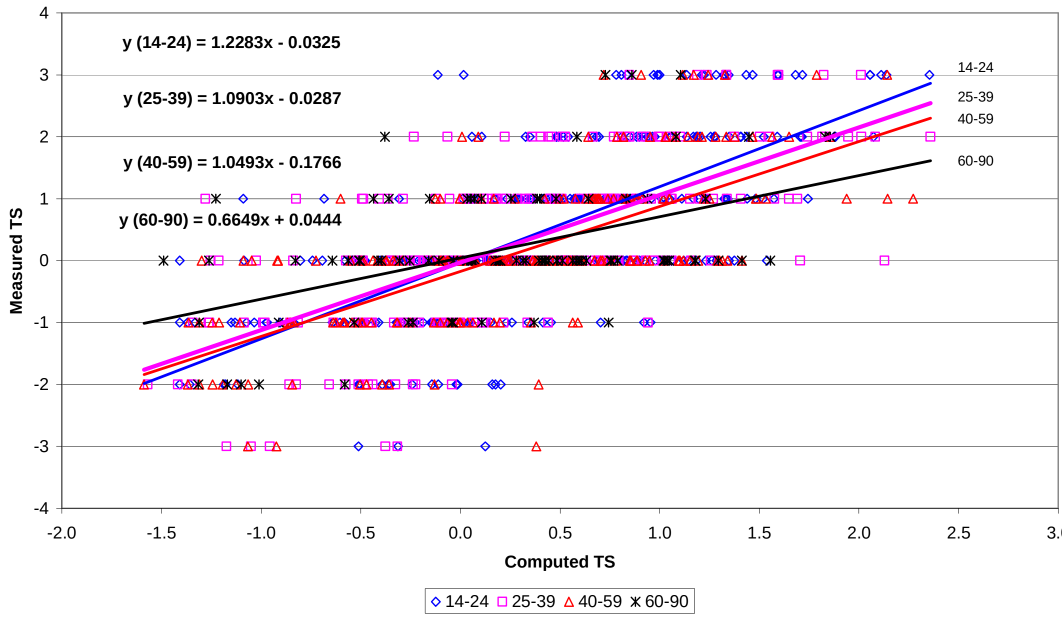

Figure 6: Age effect on sensitivity of female subjects to heat and cold

Impact of body weight on thermal sensation

Figure 7 shows the impact of body weight on the thermal sensations of male and female respondents, separately. This figure suggests that the weight of the person has a greater effect on the thermal sensation of female subjects than in the case of male subjects.

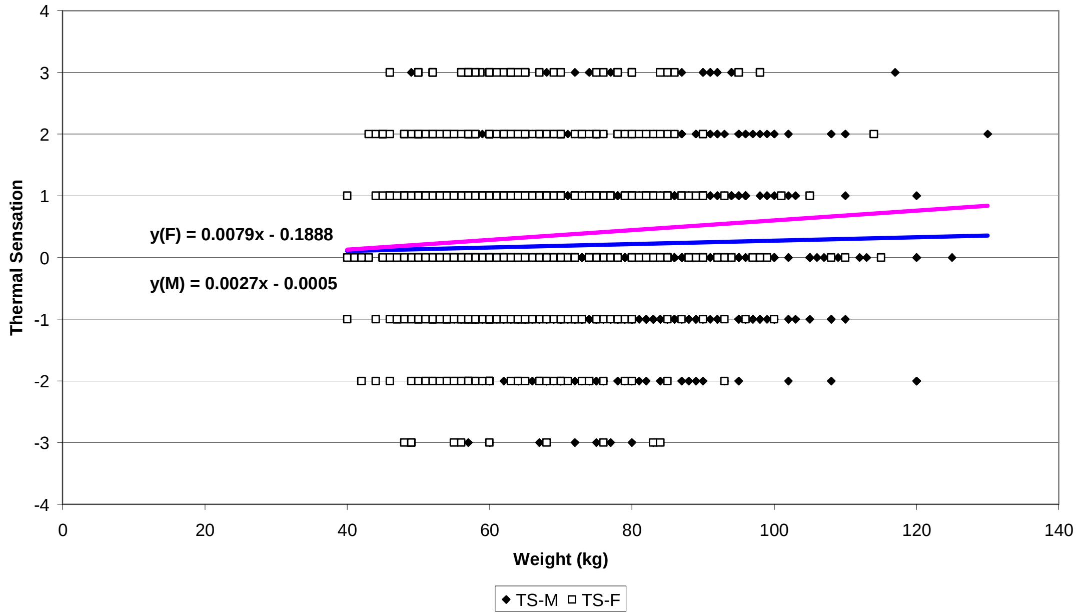

Figure 7: Body weight effect

4.3 Discussion

Regarding gender differences, it has been observed that while under comfortable conditions, the responses of men and women were about the same, thermal sensitivity of women tend to be more exacerbated under cooler and warmer conditions. Parsons (2004) obtained similar results from an indoor comfort study under constant air humidity, no radiant heat sources and constant humidity ratio, where women and men, with identical clothing, have been exposed to a set of temperature conditions over 3 h sessions. Under cool conditions, thermal sensation of female subjects was more evident (at 18.5ºC, the difference comprised of one point in the PMV scale, -1 for male and -2 for female subjects). However, for hotter conditions, Parsons found that thermal sensations would be quite similar, irrespective of gender aspects. Another comfort interview survey with a total of 3094 respondents by means of controlled experiments showed however that females are more critical of their thermal environments**,** feeling both uncomfortably cold and uncomfortably hot more often than males (Karjalainen 2006**)**. In our study, as higher air temperatures are associated with increased MRT and the latter departs in most cases quite substantially from the former, hotter conditions may not be comparable to Parsons'. It could be that women are more affected by direct solar radiation and, thus, to higher MRTs, than men.

Concerning thermal sensitivity as a function of age differences, for male subjects under heat conditions, a clear pattern was verified: younger people showed more sensitivity to heat than older subjects, when compared to cool conditions. For the female group, differences were even larger for hot conditions.

From the obtained data, it seems that old people were less sensitive to heat, and to some extent also to cold, both in the case of male and female subjects.

Taylor et al. (1995) investigated age-related differences concerning the ability to regulate room temperature, where two groups of healthy males with different ages had the possibility to control 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 activation. At cold-induced change points, the elderly group felt colder, were less uncomfortable and felt better than the young subjects. During heat-induced changes, thermal sensation was equivalent, the elderly were more comfortable and felt better. Authors concluded that it is possible that elderly people may require a more intense thermal stimulus to elicit the appropriate behavioral responses in the home and this fact could be further linked to more frequent occurrences of dysthermia in the aged.

Another study (Collins et al. 1981) using the same research method (room temperature control with two age groups suggests that both physiological and behavioural changes contribute to the increased vulnerability of old people in cold conditions. The elderly preferred the same mean comfort temperature (22-23 ºC) but manipulated ambient temperature much less precisely than the young.

In our study, in the winter, the lesser thermal sensitivity of the elderly may also be a result of the clothing chosen by the different age groups. Figure 8 shows the experimental relationship between age and clothing insulation in this research: with higher age, respondents have tended to have clothing with higher clo values. In the summer it may be affected by the metabolic rate per body weight. Also, the elderly were mostly long-time residents of the city and acclimatized to its climate, while many newcomers were younger. These hypotheses have to be checked by more research.

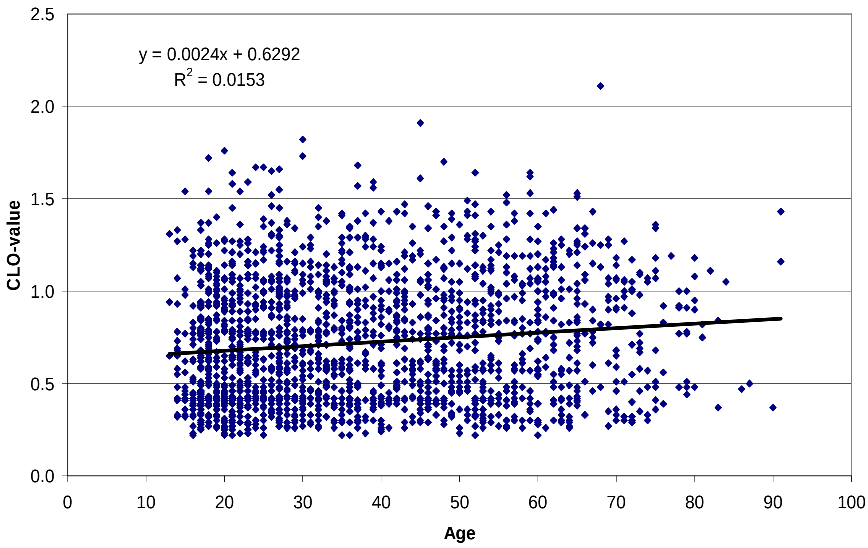

Figure 8: Clo values as related to age of the person

With regard to the impact of body weight on the thermal sensation, while the linear increase of TS with weight is expected, it has been noticed that the weight of the person has a greater effect on the thermal sensation of female subjects than in the case of male subjects. This fact may be related to the first finding, that female subjects are in general more sensitive to cool and warm conditions than men. If we take into account the relationship between body weight and height, expressed as the Body Mass Index (BMI, according to the World Health Organization), however, such differences between male and female subjects tend to be much less pronounced (Figure 9).

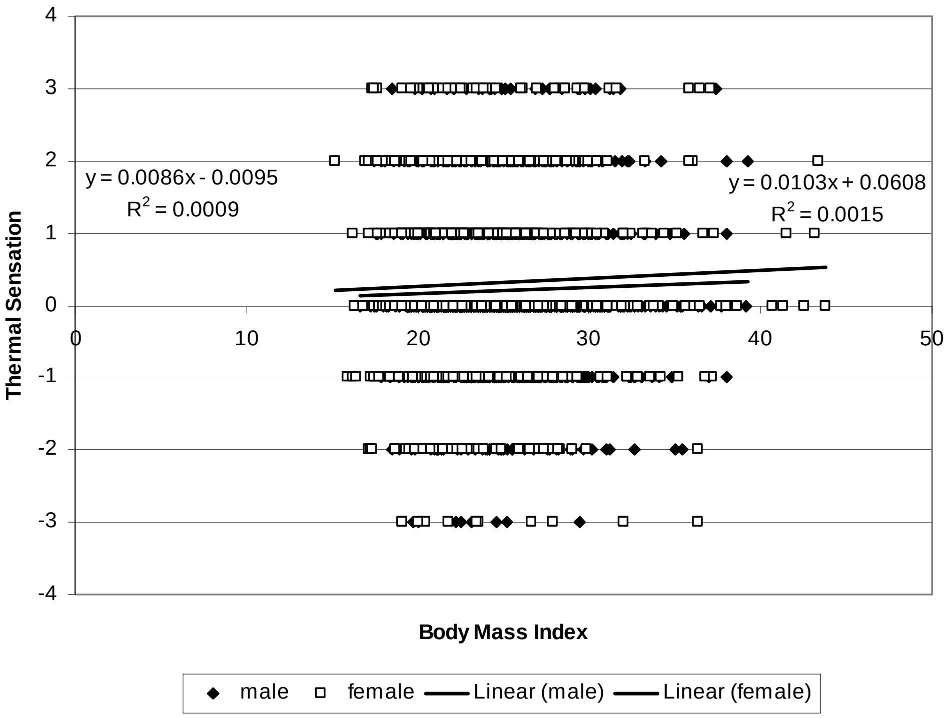

Figure 9: Body Mass Index effect

5. CONCLUSIONS

This paper shows preliminary analyses of the obtained sample of 2024 subjects and objective data gathered over the year of 2009 in pedestrian streets of Curitiba, Brazil. Although the database is large enough for various analyses, results indicate a few steps to be taken in future outdoor comfort surveys. Among such steps, following aspects should be considered in further research initiatives, which are related to the topics of this paper:

- There is a need of a careful check for more biases in the overall data, particularly regarding the factors of time of residency in Curitiba and time spent outdoors. If we don't take into account respondents who had not spent at least 15 minutes outdoors, an amount of 311 out of the total 2024 should be disregarded. If we also neglect those who were not residents by the time of the interview (less than six months living in Curitiba), the database will be reduced by 18%. Correspondingly, more interviews will be needed in order to ensure an even distribution of respondents over the wide range of climatic variations.

- A more detailed analysis is needed concerning the age effect. It may be necessary to broaden the group of elderly surveyed.

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