THERMAL COMFORT INDEX FOR SUSTAINABLE URBAN SPACES

Leonardo Marques MONTEIRO
Faculty of Architecture and Urbanism, University of Sao Paulo, Rua do Lago, 876 – Sao Paulo, Brazil

Summary

This paper presents a research that proposes a thermal comfort index, allowing the verification of the thermal adequacy of outdoor spaces in the subtropics. The method adopted is empirical, by means of field research of micro-climatic variables (air temperature, air humidity, air velocity, and mean radiant temperature), personal variables (clothing thermal insulation and metabolic rate according to activity) and subjective answers of thermal sensation and thermal comfort. The field research consists of seventy-two microclimatic situations, regarding the application of one thousand and seven hundred and fifty questionnaires. The results from the proposed equation, compared with those from the others predictive models, showed that, for the specific subtropical microclimatic conditions, they present better correlations with the data gathered.

Keywords: thermal comfort, urban spaces, predictive model

1 Introduction

Thermal comfort assessment in outdoor spaces requires the comprehension of additional factors, which are not taken into account in a typical indoor situation. Short-wave radiation and winds, considerable sweating rates or variable clothing, different human activities and expectations, among other factors, bring more complexity to the analysis. This paper presents a research that proposes a thermal comfort index, allowing the verification of the thermal adequacy of outdoor spaces in the subtropics. The method adopted is experimental inductive, by means of field research of micro-climatic variables and subjective answers, and deductive, by means of regression analysis. The significance of the results is verified by comparison with the ones obtained by simulation of predictive models.

2 Empirical research

The procedures were done following guidelines and data from [1, 2, 3, 4, 5]. On the field researches, seventy-two different micro-climatic scenarios were considered and one thousand and seven hundred and fifty questionnaires were applied during summer and winter of two consecutive years, in the city of Sao Paulo, Brazil. The procedures are briefly presented in the following paragraphs.

For the measurements and application of questionnaires, three bases were set: the first one under open sky, the second one shaded by trees, and the third one under a tensioned membrane structure. In each one of the three bases, micro-climatic variables (mean radiant temperature, air temperature, air humidity and wind speed) were measured and a hundred and fifty people answered a questionnaire, in six different hours of the day. These people came from different regions of Brazil. Further studies will consider not only the results from acclimatized ones, but also comparatively the results from those who were not acclimatized. The questionnaire considered questions of personal characteristics (sex, age, weight, height), acclimatization (places of living and duration) and subjective responses (thermal sensation, preference, comfort and tolerance). Pictures were taken of everyone who would answer the questionnaire, in order to identify clothing and activity. A forth base, at 10 m high, was set for measuring meteorological parameters (global radiation and wind speed).

The equipment used in each base was the following. Under open sky: meteorological station ELE model EMS, data logger ELE model MM900 EE 475-016. Shaded by trees: meteorological station Huger Eletronics model GmbH WM918 and personal computer for data logging. Under tensioned membrane structure: station Innova 7301, with modules of thermal comfort and stress, and data logger Innova model 1221. At 10m high: meteorological station Huger Eletronics model GmbH WM921 and a piranometer Eppley. In each base, globe temperature was also measured through 15cm grey globes and semiconductor sensors, storing the data in Hobo data loggers. The measurements were done in intervals of one second, and the storage was done in intervals of one minute, considering the average of measurements.

The limits in which the empirical data were gathered are: air temperature (ta) = = 15 °C~33 °C; mean radiant temperature (mrt) = 15 °C~66 °C; relative humidity (rh) = = 30 %~95 %; wind speed (va) = 0,1 m/s~3,6 m/s. It should also be mentioned that, although it is not a limiting factor for normal situations, the maximum and minimum clothing thermal insulation values found were 0,3 and 1,2 clo, with mean values between 0,4 and 0,9 clo. Considering the Typical Reference Year (TRY) [6] for Sao Paulo, the ranges presented represent 92 % of the general climatic situations during day time. On the other hand, if it is necessary to make an extrapolation, it must be done carefully and would better be object of further researches.

3 Results

The multiple linear regression to be presented was obtained considering the data from the seventy-two microclimatic situations, regarding the application of one thousand and seven hundred and fifty questionnaires.

$$tsp = -3{,}557 + 0{,}0632 \cdot ta + 0{,}0677 \cdot mrt + 0{,}0105 \cdot ur - 0{,}304 \cdot va \quad (1)$$

with: $r = 0{,}936$; $r^2 = 0{,}875$; $r^2aj = 0{,}868$; $se = 0{,}315$; $P < 0{,}001$.

where: tsp= thermal sensation perception [dimensionless], ta = air temperature [°C], mrt = mean radiant temperature [°C], rh = relative humidity [%], v = air velocity [m/s]

Considering the thermal sensation perception (tsp), following the categories of the applied questionnaires, result from –0,5 to 0,5 means neutrality; from 0,5 to 1,5 means warm; from 1,5 to 2,5 means hot; above 2,5 means very hot; from –0,5 to –1,5 means cool; from –1,5 to –2,5 means cold; and below –2,5 means very cold.

Monteiro & Alucci [7], reviewing the state of the art of outdoor thermal comfort modelling researches, observe that there is a tendency to use equivalent temperatures instead of interpretative ranges, since an equivalent temperature itself, without an interpretative range, would give a notion of the thermal sensation, taking into account a reference environment. In this research, in order to propose an equivalent temperature model, the following assumptions to the reference environment where done: mrt = ta; rh = 50 % and va = 0 m/s. Considering these assumptions, the relationship between the air temperature of the reference environment and the thermal sensation perception is:

$$ta,re = 23{,}395 + 7{,}639 \cdot tsp \qquad (2)$$

where: ta,re = air temperature of the reference environment [^{o}C], tsp = thermal sensation perception [dimensionless].

By equations 1 and 2, the following equation is proposed, where TEP stands for the proposed Temperature of Equivalent Perception.

$$TEP = -3{,}777 + 0{,}4828 \cdot ta + 0{,}5172 \cdot mrt + 0{,}0802 \cdot rh - 2{,}322 \cdot va \qquad (3)$$

The Temperature of Equivalent Perception (TEP) of a given environment can be defined as a thermal sensation scale which presents values numerically equivalent to those of the air temperature of a reference environment (mrt = ta, rh = 50 %, and va = 0) in which the thermal sensation perception is the same to the one verified in the given environment. Following equation 2, one may observe that the air temperature of neutrality, in the case of a reference environment, is approximately equal to 23,4 °C. Yet the advantage of equivalent temperatures is the intuitive interpretation of their values, it is also interesting to provide a interpretative range, since the intuitive interpretation is only possible after the exposition to several environments and their respective equivalent temperatures. In the *Discussion* topic of this paper interpretative ranges for the Temperature of Equivalent Perception (TEP) will be proposed.

4 Discussion

The results of the proposed Temperature of Equivalent Perception (TEP) presented a correlation of 0,936 for the model parameter and for its index. The percentage of correct predictions achieved 96 %, considering the whole data gathered.

In the previous topic, it was argued that the advantage of equivalent temperatures is the intuitive interpretation of their values. On the other hand, it is also interesting to provide an interpretative range, since the intuitive interpretation is only possible after the exposition to several environments and their respective equivalent temperatures. Thus, Table 1 presents the interpretative ranges for the Temperature of Equivalent Perception (TEP), considering the results found in the empirical researches.

Tab. 1 *Temperature of Equivalent Perception (TEP)*

TEP (^{o}C)	Sensation
> 42,5	very hot
34,9 ~ 42,4	hot
27,3 ~ 34,8	warm
19,6 ~ 27,2	neutrality
12,0 ~ 19,5	cool
4,4 ~ 11,9	cold
< 4,3	very cold

5 Conclusions

The contribution of this paper is to provide a thermal comfort index which can be properly used for predicting thermal comfort in outdoor spaces in a subtropical climate. The Temperature of Equivalent Perception (TEP) presents significant correlations with the data gathered in different scenarios, providing a simple, easy-to-use and reliable index to assess thermal comfort in outdoor spaces in a subtropical climate.

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