

Definition of human thermal comfort ranges for open spaces in Santa Maria, Rio Grande do Sul (RS)

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Abstract: Thermal comfort index has been used to evaluate the average perception of people regarding weather conditions in several regions of the globe, although very little with respect to the subtropical region of Brazil, particularly in southern Brazil. Therefore, this study aimed to define a range of thermal comfort suitable for residents of the Santa Maria city, Rio Grande do Sul, based on perception / feeling questionnaires to the inhabitants, simultaneously to the meteorological data records between days 05 From August to August 7, 2015, from January 17 to January 19, 2016 and from July 6 to July 8, 2016. Primary data were collected on air temperature, gray globe temperature, relative humidity, wind speed, wind gust, global solar radiation and rainfall. Interviews were conducted on people aged between 18 and 60 years, with body coverage between 0.5 and 1.0 clo. In this study, it was concluded that the statistical modeling was effective in determining the thermal comfort ranges adequate to the climatic patterns and the thermal preference of the population of Santa Maria, Rio Grande do Sul. However, based on the statistical analysis applied, the conclusion is that none of these indexes, as originally constructed, in fact ideal for explaining the thermal comfort in Santa Maria, being necessary the adaptation of these, or a new index construction, in order to have a better explanation.

Keywords: *Subtropical climate, thermal comfort ranges, thermal sensation.*

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Introduction

To evaluate the average perception of people regarding weather conditions, several ranges of human thermal comfort have already been established (HÖPPE, 2002; SPAGNOLO; CARO, 2003; GULYAS *et al.*, 2006; CHENG; NG, 2006; MONTEIRO; ALUCCI, 2007; BRÖDE *et al.*, 2012; ROSSI, *et al.*, 2012; PANTAVOU, *et al.*, 2013; LAI *et al.*, 2014). Typically, the tools used to build this type of scale are a questionnaire that contains questions about the respondents' personal impressions of the weather at the time of its use. They are combined with a meteorological station, which measures several weather variables, such as temperature, relative air humidity, and wind speed, simultaneously with the application of the questionnaire (ISO 10551, 1995; ISO 7726, 1998; ISO 8996, 2004; ISO 9920, 2007; JOHANSSON *et al.*, 2014).

However, no scale of this type has been created in the subtropical region of Brazil using the Houghton and Yaglou Effective Temperature (ET) (HOUGHTEN; YAGLOGLOU, 1923) index and the Effective Temperature with Wind Index (ETw), Rossi *et al.* (2012) only use the Universal Thermal Climate Index (UTCI) (ISB - International Society of Biometeorology) for the adaptation of the thermal comfort ranges in Curitiba, Paraná (PR).

Thus, we seek to define a range of thermal comfort suitable for the residents of the city of Santa Maria, Rio Grande do Sul, based on the application of perception/sensation questionnaires to the inhabitants combined with simultaneous records of the local meteorological attributes.

Material and methods

To implement the proposal to define the thermal comfort ranges suited to the thermal sensation of the population of Santa Maria (Fig. 1a), meteorological and thermal sensation data were collected. To that end, an automatic weather station (AWS), Campbell CR-1000, with a maximum height of 2.0 m, was used on a mobile aluminium tripod (Fig. 1b). The AWS used the following sensors: a tipping bucket rain gauge; a global radiation sensor; an air temperature and humidity sensor; a wind speed and direction sensor; and a grey globe thermometer.

The primary air temperature data and grey globe temperature data were collected – given that the station was installed in an open area with an incidence of direct solar radiation (ISO 7726, 1998) – as well as the relative humidity of the air, wind speed, wind gust, global solar radiation, and rainfall.

The air temperature, relative humidity, and solar radiation sensors were positioned at a height of 1.5 m from the ground, whereas the wind speed and direction sensor was installed at a height of 2.0 m, at the top of the structure.

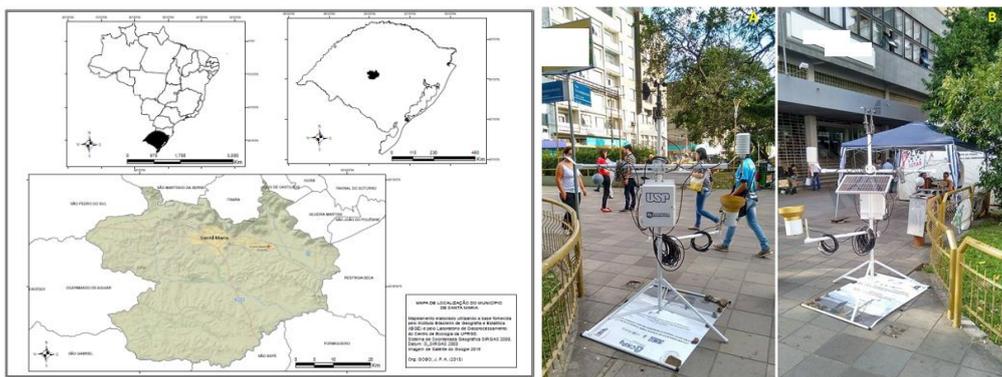


Figure 1: Location of the study area (Fig. 1a) and the installation site of the weather station (Fig. 1b) (north view A, south view B).

The weather station was installed in a paved area of Saldanha Marinho Square, in the centre of the city of Santa Maria, where there is an intense flow of people, and data were recorded every 10 (ten) minutes in August 2015 and every 20 (twenty) minutes in the other periods.

The field sampling period was from 5 to 7 August 2015, from 17 to 19 January 2016, and from 6 to 8 July 2016, with the collection of meteorological data and interviews with the local population occurring between 09:00 and 17:00 of the solar time on each of these days and periods of the survey.

In the analysis period of August 2015, 6 (six) people were interviewed every 10 (ten) minutes (in concurrence with the meteorological data collection by the station) and 6 people every 20 minutes in the other periods (January and July), totalizing 834 interviews during the 3 days.

Only people who had lived in the municipality for more than 1 (one) year were interviewed, due to the individuals' thermal history and their environmental memory, as noted in the research by Nikolopoulou (2001).

The interviews were also limited to people aged between 18 and 60 years who did not seem overweight or underweight. A covered body surface area standard of 0.5 to 1.0 clo was established, corresponding to an individual in jeans and a T-shirt and to an individual in a suit, respectively (ISO 9920, 2007). A 300 W physical activity pattern was assumed for each interviewed individual, given that only people in movement (walking) were interviewed (ISO 8996, 2004).

Regarding the questionnaire applied, an adaptation of the model established by the ISO 10551 (1995) standard was used, in which the basic question of the study was:

Question 1 – At this very moment, I am feeling:
() very cold; () cold; () slightly cold; () neither cold nor hot; () slightly hot; () hot; () very hot.

After the interpretation of the weather for the research days, the weather data from the Mobile-AWS were used to calculate the Effective Temperature Index with Wind (ET_w) of Suping *et al.* (1992) (Equation 1), the Effective Temperature Index (ET) of Houghton and Yaglou (1923) (Equation 2) and the Universal Thermal Climate Index (UTCI) developed by the International Society of Biometeorology, calculated using the Bioklima © 2.4. software.

for $v > 0.2$ m/s

Equatio 1:

$$ET_w = 37 - (37 - T) / \{0,68 - 0,0014 \cdot HU + [1 / (1,76 + 1,4 v 0.75)]\} - 0,29 \cdot T \cdot (1 - 0,01 \cdot HU)$$

for $v \leq 0.2$ m/s

Equatio 2:

$$ET = T - 0,4 \cdot (T - 10) \cdot (1 - 0,01 HU)$$

Where: T = Air Temperature (°C); HU = Relative Humidity (%); v = Wind Velocity (m/s).

Regarding the thermal perception of the population, the different subjective responses to the questionnaire received a numerical value according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers/American National Standards Institute (ASHRAE/ANSI) 55 scale, which ranges between -3 and 3 for the perception responses of: very cold -3; cold -2; slightly cold -1; neither cold nor hot 0; slightly hot 1; hot 2; and very hot 3.

Finally, the data were submitted to two multiple linear regression models (NETER; WASSERMAN; KUTNER, 1990) defined to validate the analyses and define the comfort ranges for each used index.

Results and Discussion

When analyzing the distribution of the thermal comfort indices calculated by the weather variables of each time combined with the respondents' answers to question 1, we intended to identify an index that could satisfactorily describe the thermal comfort of the population of Santa Maria.

The ET_w index (Fig. 2a) shows a desired linear behaviour (increasing), particularly for cold levels. However, it shows problems at the hot levels (1, 2, and 3), with little variation in the median because the responses tend towards the hotter, particularly compared to the values corresponding to responses 1 (slightly hot) and 2 (hot). The variability is also high, particularly in the observations corresponding to category 0 (neither cold nor hot), which are distributed over almost the entire range encompassed by the other categories.

The UTCI index (Fig. 2b) shows little median variation between levels for the cold categories (-3, -2, and -1). The increasing number of outliers, however, indicates a slight increase in the mean. The neutral category (0) presents high variability in this index, in addition to the hot categories.

On the other hand, the ET index (Fig. 2c), has an increasing trend, and the variability is slightly lower in the hot categories (1 to 3) but with a larger number of outliers, indicating that the amplitude is similar.

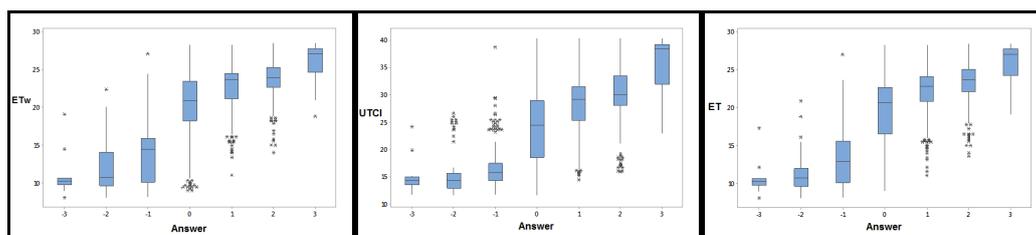


Figure 2: Comparative boxplot of the ETw (Fig. 2a), UTCI (Fig. 2b), and ET (Fig. 2c) index measurements according to the answer to question 1.

Due to the impossibility of creating a new index suited to Santa Maria's climatological and subjective patterns, the definition of new cut-offs for the previously created and calculated indices for the observed days becomes an effective solution.

To do so, we opted to use two multiple linear regression models (NETER; WASSERMAN; KUTNER, 1990) with the use of a code to optimise the correctness ratio of the models through changes in cut-off points. The optimized values are shown in Table 1, which illustrates the idea of the procedure, which is to find bands with sizes that maximize the number of points considered correct.

Table 1: Classes associated with each score interval after calculation of optimized cut-off points and index hit rates after the optimization of their cut-off points.

Classes	Score	Index	Index hit rates
Very cold	$(-\infty ; -2,379]$	ETw	31,5%
Cold	$(-2,379 ; -1,335]$	UTCI	44,8%
Slightly cold	$(-1,335 ; -0,254]$	ET	45,6%
Neither cold nor hot	$(-0,254 ; 0,965]$		
Slightly hot	$(0,965 ; 1,412]$		
Hot	$(1,412 ; 2,040]$		
Very hot	$(2,040 ; +\infty)$		

The post-optimization hit rates, shown in Table 1, show the effectiveness of this method. The hit ratios and estimate ratios of each index that are within one unit distance of the class declared by the respondent are presented in Table 2. The cut-off points for the indices that were obtained through this process are shown in Table 3.

Table 2: ETw, UTCI and ET index prediction results using optimized cut-off points.

	ETw			UTCI			ET		
	Hit	Difference ≤ 1	Total	Hit	Difference ≤ 1	Total	Hit	Difference ≤ 1	Total
Aug/2015	284 (33,1%)	700 (81,7%)	857	361 (42,1%)	638 (74,4%)	857	381 (44,5%)	661 (77,1%)	857
Jan/2016	77 (17,8%)	256 (59,3%)	432	205 (47,5%)	350 (81,0%)	432	206 (47,7%)	355 (82,2%)	432
Jul/2016	180 (41,8%)	366 (84,9%)	431	205 (47,6%)	388 (90,0%)	431	197 (45,7%)	393 (91,2%)	431
Total	541 (31,5%)	1322 (76,9%)	1720	771 (44,8%)	1376 (80,0%)	1720	784 (45,6%)	1409 (81,9%)	1720

Table 3: Cut-off points between the classes of the response to question 1 variables optimized for each index.

Classes	ETw	UTCI	ET
Very cold	< 7	<12	<4
Cold	7 – 14	12 – 15	4 - 8
Slightly cold	14 – 15	15 – 16	8 – 15
Neither cold nor hot	15 – 22	16 – 27	15 – 22
Slightly hot	22 – 38	27 – 28	22 – 23
Hot	38 – 46	28 – 36	23 - 26
Very hot	>46	>36	> 26

Conclusions

Considering the objectives proposed at the beginning of this research, it is concluded that the statistical modelling was effective in determining the thermal comfort ranges suitable for the climate patterns and the thermal preference of the population of Santa Maria, Rio Grande do Sul.

Finally, from the applied statistical analysis, it can be said that none of these indices, as originally created, in, in fact, ideal for explaining the thermal comfort in Santa Maria, and it is necessary to adapt them, or create a new index, so that it is explained in a satisfactory manner.

References

- ANSI/ASHRAE Standard 55. (2013) **Thermal Environmental Conditions for Human Occupancy**. Atlanta: American society of heating, refrigerating, and air-conditioning engineers.
- Bröde, P.; Krüger, E. L.; Rossi, F. A.; Faila, D. (2012) Predicting urban outdoor thermal comfort by the Universal Thermal climate index UTCI – a case study in Brazil. **Int. J. Biometeorol.** 56, 471–480.
- Cheng, V.; Ng, E. (2006) Thermal comfort in urban open spaces for Hong Kong. **Architectural Science Review**, 49(3), 236–242.
- Gulyas, A.; Unger, J.; Matzarakis, A. (2006) Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. **Building and Environment**, 41, 1713–1722.
- Höppe, P. (2002) Different aspects of assessing indoor and outdoor thermal comfort. **Energy Build.** 34, 661–665.
- Houghten, F. C.; Yaglou, C. P. (1923) Determining lines the equal comfort and Determination of the comfort zone. In: **ASHVE Transactions**, v.29.
- ISO 10551 (1995) Ergonomics of the Thermal Environment – Assessment of the Influence of the Thermal Environment Using Subjective Judgement Scales. **International Organization for Standardization**, Geneva.
- ISO 7726 (1998) Ergonomics of the Thermal Environment – Instruments for Measuring Physical Quantities. **International Organization for Standardization**, Geneva.
- ISO 8996. (2004) Ergonomics of the Thermal Environment – Determination of Metabolic Rate. **International Organization for Standardization**, Geneva.
- ISO 9920. (2007) Ergonomics of the Thermal Environment – Estimation of Thermal Insulation and Water Vapour Resistance of a Clothing Ensemble. **International Organization for Standardization**, Geneva.
- Johansson E.; Thorsson S.; Emmanuel R.; Krüger E. (2014) Instruments and methods in outdoor thermal comfort studies – The need for standardization. **Urban Climate** v. 10, 346–366.
- Lai D., Guo D.; Hou Y.; Lin C.; Chen Q. (2014) Studies of outdoor thermal comfort in northern China. **Building and Environment**, 77, 110-118.
- Monteiro, L. M.; Alucci, M. P. (2007) Questões teóricas de conforto térmico em espaços abertos: consideração histórica, discussão do estado da arte e proposição de classificação de modelos. **Ambiente Construído**, v. 7, n. 3, p. 43-58.
- Neter, J. E Wasserman, W. E Kutner, M. H. (1990). **Applied Linear Statistical Models**, 5ª ed. Illinois: Irwin, 1.181p.
- Nikolopoulou, M.; Baker, N.; Steemers, K. (2001) Thermal comfort in outdoor urban spaces: understanding the human parameter. **Sol. Energy** 70, 227–235.
- Pantavou, K.; Theoharatos, G.; Santamouris, M.; Asimakopoulos, D. (2013) Outdoor thermal sensation in a Mediterranean climate and a comparison with UTCI. **Building and Environment** 66, 82-95.
- Rossi, F. A.; Krüger, E. L.; Bröde, P.; (2012) Definição de faixas de conforto e desconforto térmico para espaços abertos em Curitiba, PR, com o índice UTCI. **Ambiente Construído (Online)**, v. 12, p. 41-59.
- Spagnolo, J.; Dear, R. (2003) A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. **Building and Environment**, 38(5), 721–738.
- Suping, Z.; Guanglin, M.; Yanwen, W.; Ji, L. (1992) Study of the relationships between weather conditions and the marathon race, and of meteorotropic effects on distance runners. *International Journal of Biometeorology*, 36, 63-68.