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COMPARISON AND CALIBRATION OF COMFORT INDICES FOR THE WARM SEASON IN A SEMI-ARID CITY OF NORTHWESTERN MEXICO

COMPARATIVA Y CALIBRACIÓN DE ÍNDICES DE CONFORT PARA LA TEMPORADA CÁLIDA EN UNA CIUDAD SEMI-ÁRIDA DEL NOROESTE DE MÉXICO

COMPARAÇÃO E CALIBRAÇÃO DE ÍNDICES DE CONFORTO PARA A ESTAÇÃO QUENTE EM UMA CIDADE SEMIÁRIDA DO NOROESTE DO MÉXICO

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RESUMEN

El análisis sobre modelos de confort y el efecto de las condiciones microclimáticas extremas es importante para determinar la relación entre las afectaciones de salud en personas que realizan actividades en áreas abiertas. El trabajo propone un modelo psicofisiológico regional, para individuos con actividades físicas intensas (deportivas) en espacios públicos exteriores en clima cálido seco extremoso (Mexicali, Baja California), el que se contrastó con el Universal Thermal Climate Index con el propósito de calibrarlo y así establecer una base comparativa para formular pruebas de hipótesis que evalúen su aplicabilidad. Se encontró que el modelo regional alcanzó un 67% de aciertos en comparación del Universal Thermal Climate Index que obtuvo 31% de aciertos no calibrado y 53% de aciertos calibrado. Como conclusión de este proceso se destaca la pertinencia, precisión y eficiencia en la utilización de modelos específicos regionales sobre aquellos que tienden a generalizar las condiciones de la percepción térmica.

Palabras clave
modelo psicofisiológico, confort térmico, actividad intensa, calibración de escala.

ABSTRACT

The analysis of comfort models and the effect of extreme microclimatic conditions is vital to determine the relationship between health affectations in people who perform activities in open areas. This work proposes a regional psychophysiological model for individuals with intense physical activities (sports) in outdoor public spaces in an extremely hot dry climate (Mexicali, Baja California), which was contrasted with the Universal Thermal Climate Index to calibrate it and thus establish a comparative basis to formulate hypothesis tests to evaluate its applicability. It was found that the regional model achieved 67% accuracy compared to the Universal Thermal Climate Index, which obtained 31% accuracy when not calibrated and 53% accuracy when calibrated. The conclusion of this process highlights the relevance, accuracy, and efficiency of using specific regional models over those that tend to generalize the thermal perception conditions.

Keywords
psychophysiological model, thermal comfort, intense activity, scale calibration.

RESUMO

A análise dos modelos de conforto e o efeito das condições microclimáticas extremas são importantes para determinar a relação entre as complicações de saúde em pessoas que realizam atividades em áreas abertas. O artigo propõe um modelo psicofisiológico regional para indivíduos com atividades físicas intensas (esportivas) em espaços públicos externos em clima quente e seco extremo (Mexicali, Baja California), que foi contrastado com o Universal Thermal Climate Index para ser calibrado e, assim, estabelecer uma base comparativa para formular testes de hipóteses para avaliar sua aplicabilidade. Verificou-se que o modelo regional alcançou uma taxa de precisão de 67% em comparação com o Universal Thermal Climate Index, que obteve 31% de precisão sem calibração e 53% de precisão com calibração. A conclusão deste processo destaca a relevância, a precisão e a eficiência do uso de modelos regionais específicos em relação àqueles que tendem a generalizar as condições de percepção térmica.

Palavras-chave:
modelo psicofisiológico, conforto térmico, atividade intensa, calibração de escalas.

INTRODUCTION

Nowadays, thermal comfort and its effect on health is a concern (Peng et al., 2019), especially the thermal perception of individuals doing sports activities in outdoor public spaces. As mentioned by Nikolopoulou and Lykoudis (2006) and Manavvi and Rajasekar (2022), this is a feature that contributes to the quality of the urban environment, helps increase occupancy levels and use, and supports leisure, recreation, and health-related activities (Lai et al., 2020).

Thermal comfort can be understood in different ways. On one hand, it is the individual's mental satisfaction with the thermal environment. On the other hand, it can also be their physiological and psychological satisfaction with this environment (ISO 7730, 2006; Nikolopoulou & Lykoudis, 2006; Manavvi & Rajasekar, 2021). In this sense, the convergence of the subjective and objective parts of thermal perception and the search for comfort are determined in the adaptive processes. Even so, thermal comfort is a complex process to define, evaluate, and study, making it difficult to establish an appropriate concept (Dashrath-Khaire et al., 2021).

Hence, researching the effects climates have on individuals' health is essential today (González-González, 2021). New trends have focused on understanding the relationship between weather conditions and individual's thermal perception in outdoor public spaces and, as in the case presented, for intense sports activities (metabolic rate 600w/m^2) and in extreme dry hot climates (de Dear, 2011; Candido et al., 2012; Fernández García et al., 2012; Tumini et al., 2015; Jiaqi et al., 2022; Liu et al., 2023).

The literature reviews list up to 140 comfort indices (Epstein & Moran, 2006; Carlucci & Pagliano, 2012; De Freitas & Grigorieva, 2015). Hence, the relevance of studies that develop and compare indices that aim to establish, measure, and validate people's thermal responses.

It is important to mention that there are different types of comfort models: univariate ones such as those developed by Martínez-Bermúdez y Rincón-Martínez (2024), Nuñez et al. (2024), Martín del Campo et al. (2020), Rincón et al. (2020), López-Cañedo et al. (2021), and Bojórquez et al. (2014) that consider the correlation between a meteorological variable and thermal sensation. On the other hand, there are multivariate models and temperature indices, such as the Actual Sensation Vote – ASV - (Nikolopoulou & Lykoudis, 2006), the Standard Effective Temperature, -SET-, Predicted Mean Vote – PMV and the Universal Thermal Climate Index (UTCI), developed to link meteorological conditions with thermal sensation (Fang et al., 2019). These are based on the user's thermal balance with the surrounding environment, the processes of human thermoregulation (physiological aspects: metabolism, sex, age, health status), and psychological aspects (adaptation, tolerance, expectation, and experience, in some cases).

Numerous indexes have evaluated comfort in indoor spaces. However, only a few can be used to evaluate thermal perception and comfort in outdoor spaces. There are fewer still on people who do sports or intense activities in their different magnitudes - as is the case of the model in this work - making studies more complex due to the alteration of people's metabolic, thermoregulation, and thermal balance issues. Thus, developing a comfort index or model is further complicated by the specific characteristics of open urban spaces and the users' conditions (Johansson, 2006), given the different aspects of the sensation and thermal comfort process (expectation, experience, adaptation, clothing, exposure time, etc.) involved. Psychological and cultural aspects have also begun to be considered for their development. (Jendritzky, de Dear & Havenith, 2012).

UTCI is one of the most widely used indices and is currently a reference for developing other physiological adaptation models to generate equivalent temperature indices (Jendritzky, de Dear & Havenith, 2012). Studies such as those of Tumini and Pérez (2015) and more recent ones like Jing et al. (2024), Liu et al. (2023), Boussaidi et al. (2023), Manavvi and Rajasekar (2023), and Ghani et al. (2021), Barcia-Sardiñas et al. (2020), and Marchante y González (2020), have compared it with other similar indices to demonstrate its reliability and applicability by correlating its results and thus establishing its efficiency when applied. In some cases, comparisons and calibrations have been made, such as those by Monteiro and Alucci (2009), establishing the indices' applicability or efficiency.

Thus, based on the aforementioned works, to compare the indices, it must be considered that both are calculated using meteorological variables that affect thermal comfort in outdoor spaces and that both can evaluate the thermal sensation using a numerical value associated with a qualitative scale of perception and quantitative meteorological variables.

Hence, this article aims to establish the reliability of applying a physiological-rational adaptation model

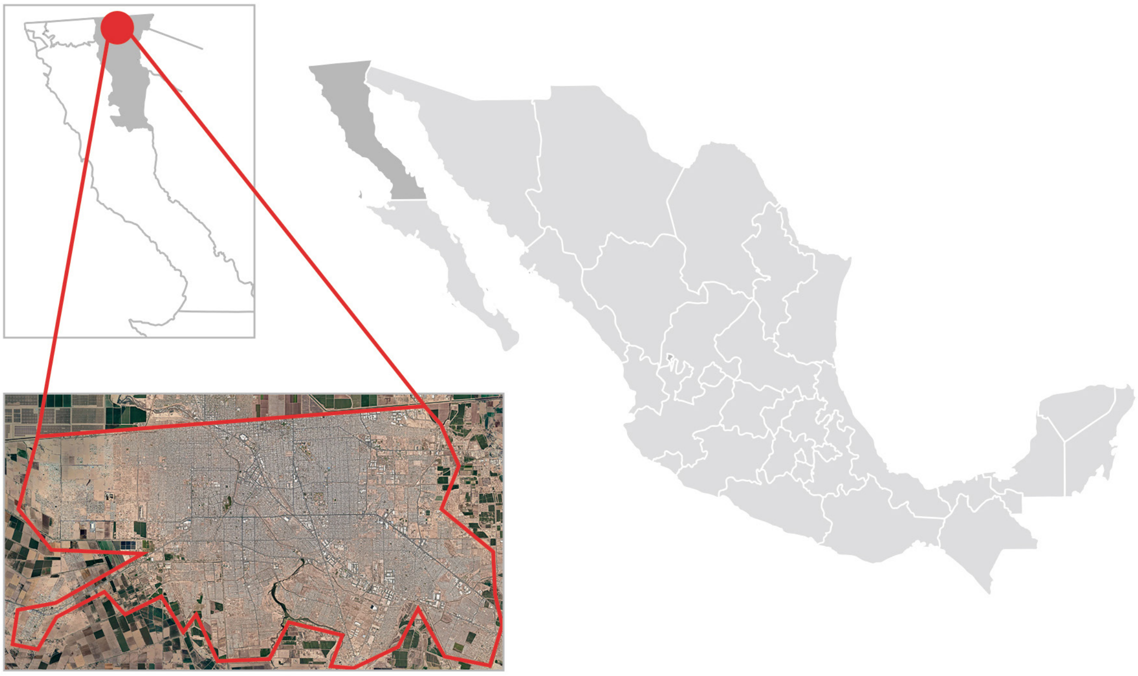

Figure 1.- Mexicali, Baja California. Source: Preparation by the author.

and a psychophysiological-empirical adaptation model by comparing both under intense sports conditions in a hot, dry climate. To determine how applicable the UTCI is under these characteristics and establish its reliability in similar conditions, the study was run using TSV (Thermal Sensation Vote) simulations with the indices and a comparative analysis of the results obtained to determine the accuracy of each one. In addition, the discussion was reinforced with statistical analyses to validate the results.

METHODOLOGY

The comparison of both thermal comfort indices is based on an understanding of the region and the climatic conditions. For this, the UTCI model was described and characterized, and a description of the regional model was generated. Finally, the simulation process and statistical analysis of the data were detailed.

LOCATION OF THE APPLICATION AREA

Mexicali is located in northwest Mexico (Figure 1), at 32.65° N and -115.45° W. According to the Köppen-García classification, its climate is extremely hot and dry [BW (h") hs (x") (e")]. Its average annual temperature is higher than 23.0 °C and lower than 18.0 °C in the coldest month. The characteristics of the warm period are: normal maximum average temperature of 42.0 °C and extreme highs above 50.0 °C; the relative humidity of the period ranges between 10% and 65%; wind speed ranges between 0.10 m/s to 4.0 m/s, and there is an average Solar Radiation of 937 W/m^2 in July.

UTCI INDEX

The UTCI is a physiological adaptation model that can be applied to diverse regions. It was developed from non-acclimatized subjects in outdoor spaces and under variable meteorological conditions. Its purpose is to provide information to avoid adverse climatic effects on health and as a tool to see the impact of climate change on aspects of population morbidity and mortality (Jendritzky, de Dear & Havenith, 2012).

It is established as an "equivalent temperature" (ET) index of the reference environment, under a physiological response criterion with exposures of 30 and 120 minutes, and expressed in degrees Celsius (°C) equivalent on the thermal stress values scale (Table 1) (Bröde et al., 2012). It uses the meteorological variables of air temperature (°C), mean radiant temperature (°C), relative humidity (%) or water vapor pressure (hPa), and wind speed (m/s).

The index is calculated using a multiple linear regression model (Błażejczyk & Kunert, 2011), whose expression is shown in Equation 1.

Table 1.- Equivalent temperature scale of the UTCI index. Source: Taken from the UTCI Assessment Scale: UTCI categorized in terms of thermal stress

UTC range (°C eq)	Stress Category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	Without heat stress
+9 to 0	Slight cold stress
0 to -13	Moderate cold stress
-13 to -27	Strong cold stress
-27 to -40	Very strong cold stress
Below -40	Extreme cold stress

Note: °C eq means equivalent degrees Celsius

$$UTCI^* = 0.84 \cdot ta + 0.246 \cdot Tmrt - 2.45 \cdot v + 0.204 \cdot vp - 0.01$$

(Equation 1)

Where:
UTCI* = equivalent temperature index (°C)
DBT = air temperature (°C).
MRT = mean radiant temperature (°C).
WS = wind speed at 10 m above ground level (m/s).
VP = ambient vapor pressure (hPa).

REGIONAL PSYCHOPHYSIOLOGICAL MODEL (VSTAI)

The VSTai (Thermal Sensation Vote- Intense Activity) uses the ISO 10551 standard as a reference. This latter establishes thermal sensation votes using subjective and objective perception scales linked to climatic variables through statistical correlation analysis (Pearson). These scales are dry bulb temperature (DBT), Relative Humidity (RH), Wind Speed (WS), Solar Radiation (SR), and Mean Radiant Temperature (Mrt) (Table 2). Using them, a multivariate mathematical statistical model is developed (Jiaqi et al., 2022; Sarhadi & Rad. 2020).

The calculated sample consisted of 300 surveys, with a reliability of 95%. The season analyzed is the warm season (May-September). 332 observations were collected, providing data for the model's generation. In total, 10% more surveys were taken than planned, providing sufficient margin to discriminate those that did not have the necessary data quality while retaining a representative sample.

Table 2.-Correlations of meteorological variables with the thermal sensation. Source: Preparation by the author.

Meteorological variable	Coeficiente Pearson
Ta	0.53
Hr	0.23
V	0.16
Rs	0.07
Trm	0.52

Sample, collection, and analysis of data to develop the model

For the field data collection, an instrument was prepared using the criteria of the current comfort regulations (ISO 10551, 2019; ISO 7730, 2006; ISO 7726, 1998; ISO 9920, 2007), creating a questionnaire with an eight-part structure: Control data, thermal perception, light and acoustic perception, thermal history, physiological data, insulation by clothing, meteorological variables and characteristics of the built environment. In total, the instrument has 59 reagents (Table 3).

In the meteorological data collection, the instruments were placed within no more than 10 meters of the surveyed individuals (Figure 2) to comply with the provisions of ISO 7730. Readings of the analyzed variables (DBT, RH, WS) were taken, and these complied with the regulations of ISO 7726 (Table 4). Complementary tools were used to collect the individuals' physiological data, such as scales, tape measures, infrared skin and ear thermometers, and blood pressure monitors, which were collected to calculate the metabolic rate and heat production. Although these data were important in the study, they were not directly input into the VSTai model.

Table 3.- Questions of the instrument to collect thermal perception data. Source: Preparation by the author.

Section	Type of question	Response scale (qualitative and numerical)						
		1	2	3	4	5	6	7
Thermal perception	How are you feeling right now?	Very cold	Cold	Slightly cold	Neither hot nor cold	Slightly hot	Hot	Very hot
	How would you prefer to feel right now?	Much colder	Colder	A little colder	Unchanged	A little warmer	Hotter	Much hotter
	How are you feeling right now regarding the humidity?	Very wet	Wet	Slightly wet	Normal	Slightly dry	Dry	Very dry
	What would you prefer regarding humidity at the moment?	Much wetter	Wetter	A little wetter	Unchanged	A little drier	Drier	Much drier
	What do you feel the wind is like at the moment?	No wind at all	Some wind	Pleasant wind	Slightly strong	Very strong		
	How would you prefer the wind to be at the moment?	Less windy	Unchanged	Windier				
	What do you feel the solar radiation is like on your skin right now?	No radiation at all	Some radiation	Pleasant radiation	Somewhat strong radiation	Very strong radiation		
	How would you prefer the solar radiation to be on your skin right now?	Less radiation	Unchanged	More radiation				
	What do you feel the climate is like in this place?	Generally acceptable	Generally unacceptable					
	How tolerable does the weather seem to you at the moment?	Perfectly tolerable	Tolerable	Between tolerable and intolerable	Intolerable	Extremely intolerable		

Table 4. Meteorological instrument specifications. Source: Preparation by the author.

	Equipment used		
Equipment characteristics	ExTech 30 thermal stress monitor	A10 one-way anemometer	Dr. Meter SM206 Radiometer
Parameter -unit	Dry bulb temperature (DBT, °C) and relative humidity (RH, %)	Wind speed (WS, m/s)	Solar radiation (SR W/m2)
Measuring range	DBT: 0 to 50 °C, ± 1°C; RH: 0 to 100%.	WS: 0.1 to 20 m/s	SR: 1-3999 W/m2
Accuracy	DBT ±0.1°C; RH: ±3%	±3%, ± 0.30.	0.1 W/m2, ±5%
Recording frequency	All take 1 sample per second.		

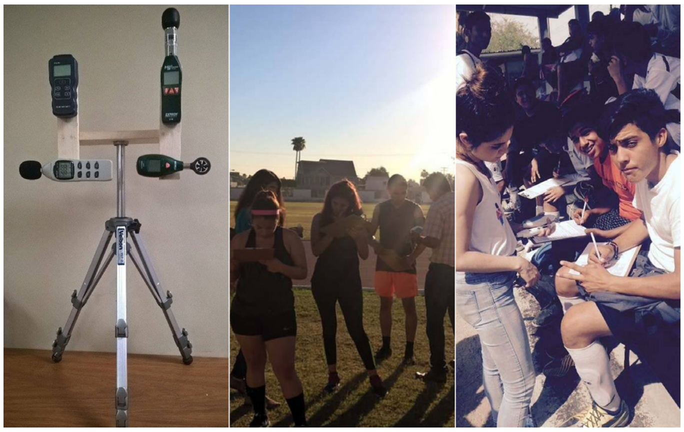

Figure 2.- Setup of instruments for meteorological data collection and survey process. Source: Preparation by the author.

Two spaces were chosen, with diverse physical activities and extended operating hours, such as the Autonomous University of Baja California sports unit and the Municipal Sports complex, "Ciudad Deportiva" (Figure 2). The fieldwork was set up considering representative days of the warm period (July 23rd to August 8th for this case), which was characterized by the following climatic conditions: DBT 30.1 °C to 40.8 °C, RH 13% to 57%, WS 0.1 m/s to 2.88 m/s, MRT (calculated) 31.2 °C to 97.6 °C.

The study population, which fluctuated between 17 and 60 years old, was selected deterministically and with an intense activity level. The survey was applied one by one or in a group (to make the process efficient), considering the type of sports activity done individually. For the thermal perception analysis, a numerical scale of 7 levels was used, ranging from very cold (1) to very hot (7) (Table 5).

Table 5. Study's Thermal Sensation Votes. Source: Preparation by the author.

ISO 10551 Thermal Sensation Vote Valorization	
7	very hot
6	hot
5	slightly hot
4	neither hot nor cold
3	slightly cold
2	cold
1	very cold

The data analysis was carried out in the Statistica 12 program. This began with Pearson correlation tests to determine the significant variables (Table 2). Then, a residual study was performed to adjust the sample's normality (those answers outside ±2 standard deviations were discriminated; a total of 3% was left out). Subsequently, the multiple linear regression model was generated (Equation 2). In it, radiation was discarded as the one with the lowest coefficient compared to the TS.

$$VSTai = 0.27 \cdot ta + 0.068 \cdot hr - 0.092 \cdot v + 0.0047 \cdot Trm - 5.95$$

(Equation 2)

Where:
VSTai = Thermal Sensation Vote in intense activity (without unit)
DBT = air temperature (°C).
MRT = mean radiant temperature (°C).
WS = wind speed at 10 m above ground level (m/s).
RH = relative humidity (%).

COMPARATIVE PROCESS OF INDICES

The comparative analysis started by transforming the VSTai model into an ET index with degrees Celsius equivalent to heat stress levels. Thus, a determined index was generated with an equivalent temperature in intense activity (ET,re, Equation 3) (Monteiro & Alucci, 2009), with the assumption of a reference environment characterized by MRT = DBT; RH = 50% and WS = 0.1 m/s; When considering this, the relationship between the air temperature of the reference environment and the perception of thermal sensation is the following:

$$Ta,re = 3.64VSTai + 9.2827$$

(Equation 3)

Where:
ET, re = reference air temperature (°C).
VSTai = Thermal Sensation Vote in intense activity.
Equation 2 is substituted in equation 3, obtaining the equivalent temperatures in intense activity model:

$$TE,ai = 0.98 \cdot ta + 0.25 \cdot hr - 0.34 \cdot v + 0.017 \cdot Trm - 12.378$$

(Equation 4)

Where:
ET,ia: temperature equivalent in intense activity (°C).
DBT = air temperature (°C).
MRT = mean radiant temperature (°C).
WS = wind speed at 10 m above ground level (m/s).
RH = relative humidity (%).

This was conceptualized as a thermal sensation scale that presented numerically equivalent values to the UTCI. This allowed the homologation of both indices and established the equivalent temperature ranges in intense activity for the VSTai scale.

A total of 332 observations collated in the database were used. The TSV was calculated with both models. The simulation was established based on the characteristics of thermal sensation in the region's warm season, subjects with intense sports activities, and extreme meteorological variables.

The calculated equivalent temperature was then associated (Equation 1 and Equation 4) to have a comparative base of the indices. Subsequently, using the empirical extrapolation of each index's stress level ranges, the numerical scale was determined to the resulting ET values of the UTCI, a standardization was generated, and a comparison was made (Table 6).

Table 6. Standardized scales between VSTai and UTCI. Source: Preparation by the author.

UTCI stress category	VST	ISO 10551 scale
Intense and/or extreme heat stress	7	very hot
Strong heat stress	6	hot
Moderate heat stress	5	slightly hot
Thermal comfort	4	neither hot nor cold
Slight cold stress	3	slightly cold
Moderate to severe cold stress	2	cold
Intense and/or extreme cold stress	1	very cold

Table 7. Comparison of model and value simulations for hypothesis testing. Source: Preparation by the author.

	Observations	Total Answers	Mean	Variance	F critical	F Calculated	Z critical	Z Calculated
TSV	332	1853	5.58	1.07	-	-		
VSTai	332	1873.31	5.73	0.18	3.86	3.36	±1.96	-1.84
UTCI eq	332	2361.1	7.11	0.59	3.86	473.19	±1.96	-21.78
UTCI eqcal	332	2111.8	6.46	0.18	3.86	463.10	±1.96	-18.63

To establish the study's relevance, comparative statistical analyses of the models were performed for the TSV. A Pearson and Spearman linear correlational analysis was conducted to establish how the results are associated quantitatively. Both coefficients were calculated to have a comparison point, which anticipated that the Spearman coefficient is robust in the presence of atypical data and thereby obtained greater certainty of the sample's normality.

On the other hand, the ANOVA variance analysis and Z-tests allowed the author to compare the group means (the TSVs and those calculated by the indices). This determined that at least some of them differed significantly between the groups. With this process, the author sought to validate the hypotheses raised about the efficiency and applicability of each model in the regional conditions.

RESULTS

The model for the city of Mexicali (VSTai) and the ET,ia index that was developed specifically for the region, were more efficient when calculating the TSV, which generally coincided with Barcia-Sardiñas et al. (2020) and Monteiro and Alucci (2009). The process results showed that a non-regional model tended to overestimate the TS (see the TSV averages in Table 7). On the other hand, the VSTai calculated a more accurate TSV, as its mean only differed by 3% compared to the responses observed in the databases.

The differences observed when calculating the TSV with the VSTai model and the UTCI are significant. The variability demonstrates greater homogeneity in the regional model by obtaining better calculations than the other index. This can be visualized when establishing the predicted means and comparing them with the TSVs collected from the subjects, where they have a difference of only 0.15 (VSTai) and 1.53 compared to the equivalent TSV for the UTCI. Even with the calibrated UTCI index, the value of its predictions continues to be very far from that of the observed votes, which is 0.86 points of the thermal perception (Table 7). This confirms the variance analysis, where the difference in the means between the TSV and the UTCI was determined and strengthened with the Z-test, which, with the calculated parameter of -1.84, corroborated the reliability of the regional model since it accepts the hypothesis of homogeneity of the mean between the TSV and the TSV that it calculated.

This is all part of regional models' greater efficiency. This corroborates what Monteiro and Alucci (2009) found, who mention that a regional model with an adaptive approach, even with fewer determination coefficients, is better at calculating the comfort vote.

It was also seen that the Pearson correlation is higher between the VSTai and the TSVs compared to the

Table 8. Correlation between the models' TSV and TS predictions. Source: Preparation by the author.

	Pearson Correlation	Spearman Correlation	Success %	Index calibration		
				Pearson Correlation	Spearman Correlation	Success %
VSTai	0.31	0.32	67	-		-
UTCI eq cal*	0.12	0.14	31	0.18	0.21	53

Note: UTCI eq cal refers to the empirical calibration made to the Universal Thermal Climate Index

Table 9. Empirical calibration of the UTCI compared to the VSTai. Source: Preparation by the author.

UTCI (°C) calibrated range	Stress Category	ISO 10551 scale	
Above +36	Extreme heat stress	7	very hot
+31 to +36	Strong heat stress	6	hot
+28 to +31	Moderate heat stress	5	slightly hot
+24 to +28	Thermal comfort	4	neither hot nor cold
+20 to 24	Slight cold stress	3	slightly cold
+17 to 20	Moderate to severe cold stress	2	cold
Below +17	Intense cold stress	1	very cold

calibrated UTCI (Table 9). The psychophysiological model's prediction effectiveness was detailed, with a success percentage of 67%, while the UTCI only had 31%. When comparing the results of the calibrated UTCI, 53% of the votes were successful, indicating that the regional model continues to obtain better statistical parameters and adapt better to the conditions.

Similarly, Spearman correlations are better in the VSTai, which validates the VSTai's reliability in the region compared to the other model and establishes greater efficiency in predicting the thermal sensation.

As a result, the calibration made to the UTCI index (Table 8) provided a better correlation with the empirical data collected and, consequently, a higher percentage of correct predictions. With this, it is inferred that using the model with a higher correlation between TSV and its predictions is appropriate. This substantiates the results found since, even when the UTCI model was calibrated, it continued with a lower success rate than the VSTai model, which, as mentioned above, matches what Monteiro and Alucci (2009) found.

On the other hand, the ET,ia Index has the best correlation between the model's parameter and the subject's responses, which also leads to improved predictions when performing its simulations. Therefore, the estimates of a thermos-physiological equilibrium and adaptation model that needs several iterations to provide reliable results (VSTai) have better results and reflect the importance of the subjects' adaptation and acclimatization to the region's meteorological conditions.

CONCLUSIONS

The comparison between the two ET indices - UTCI and ET,ia - showed that developing comfort models and indices is important when predicting the thermal perception of subjects in an outdoor environment. The VSTai model with a thermal sensation measurement scale (numerical only) is not enough, so equivalent temperature ranges must also be reflected for better application and interpretation, as used in this research, to be able to generate these comparison points (Błażejczyk et al., 2000; Monteiro & Alucci, 2011; Błażejczyk et al., 2012).

The comparative empirical study done with the UTCI allowed the results to be verified, to validate the model developed, and to establish its effectiveness through statistical hypothesis tests. This coincides with the aforementioned research, where regional models are more suitable when calculating ET and TSV (Monteiro & Alucci, 2009) and partially with that of Tumini and Pérez (2015), where the UTCI, even though it was compared with another model, did not have the same measurement scale. This contributes to strengthening researchers' interest in generating models and indices that help understand microclimatic variables' effects on people's health.

Therefore, its applicability and reliability were determined by performing a mean-variance comparison of the VSTaí results with a predictive model (even calibrated). This coincides with Monteiro and Alucci (2009), who calibrated several indices from a regional model, which showed that people's TS was still overestimated.

This work's main contribution was to provide an equivalent temperature index (ET,ia) derived from a psychophysiological model (Equation 4) that is easy to use, intuitive, and reliable and helps to evaluate thermal comfort in outdoor spaces. This work provides an understanding of how comfort can affect health in extreme climates and how the high metabolic rate, acclimatization, adaptation, and psychological aspects affect environmental perception and serve as a basis for generating early warning systems in the region.

Prospectively, it is necessary to consider:

1. Due to the limits within which the model was developed and the validation of the proposed ET,ia, it cannot be applied in other regions with other climates. It would overestimate or underestimate the thermal sensation due to the region's characteristics, people's activity levels, and urban conditions.
2. The number of observations needs to be increased to corroborate the effectiveness of the model and the ranges proposed in ET,ia
3. It would be a good idea to conduct work in different climates to the study to corroborate the model's behavior under different conditions.
4. Determine how the subjective aspect of comfort influences the increased reliability of models that are developed.

CONTRIBUTION OF AUTHORS CRediT

Conceptualization, H.E.U.B.; Data curation, H.E.U.B.; Formal analysis, H.E.U.B.; Acquisition of financing; Research, H.E.U.B.; Methodology, H.E.U.B.; Project management, H.E.U.B.; Resources; Software, H.E.U.B.; Supervision, H.E.U.B.; Validation, H.E.U.B.; Visualization, H.E.U.B.; Writing – draft original, H.E.U.B.; Writing – revision and editing, H.E.U.B.

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