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Thermal Preference: An analysis alternative approache to estimatethermalcomfort (Study case: Semi-cold bioclimate in México).

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ABSTRACT
Thermal comfort phenomenon is usually studied from thermal sensation perspectives on immediate environments from people's perception; however, there is another key factor little if anything explored in this field which reinforces this acceptance/rejection physiological process: thermal preference. It is advisable, therefore, to analyze the thermal comfort from this approach that allows to explore it as a phenomenon of individual appreciation. This study is intended to estimate the local thermal comfort through the analysis of thermal preference using a sample of young adult residents of Pachuca city, in Hidalgo, México (semi-cold climate) during extreme thermal periods of a typical year: cold and warm. The data were processed using the "Average Interval of Thermal Sensation" (MIST)method, the results were evaluated applying Auliciems & Szokolaymathematical equations [1], as well as thermal sensation values previously estimated by the author. The results showed differences in terms of reference values of comparison; suggesting that Thermal Sensation (TS) analysis provides more consistent values than those obtained via the Thermal Preference (TP) analysis. Nonetheless, it allowed to infer that while the TS values implies a tolerable thermal range scenario, the TP analysis offers the idealization of thermal pleasing conditions.
***Keywords*–**Adaptive approach, Thermal comfort, Thermal preference, Thermal sensation.

I. INTRODUCTION

Thermal comfort, according to ISO 7730 [2], "*is that condition of mind which expresses satisfaction with the thermal environment*", same aspect which in terms of ANSI / ASHRAE 55 [3]"*is assessed by subjective evaluation"*. In this sense, Auliciems [4] mentions that thermal perception is defined by the physical and psychological sensations generated by the thermal environment stimuli, activity, experience and human expectation.Virtually all the studies developed in this subject, base their results and their procedures on the individual´s thermal sensation, including ISO 7730 [2] and ANSI/ASHRAE 55 [3]. However, there is a thermal preference that simultaneously allows toconfirm in a determinant way, the acceptance or rejection of thermal conditions perceived fromenvironment. In this context, it is important to know the local thermal comfort models derived from the correlation between subject´s thermal preference and every physical variable whichinfluences his thermal perception and, therefore, the thermal comfort range.

In this sense, there are few studies that address this phenomenon from thermal preference (e.g. ISO 10551[5]; de Dear and Brager[6]). Thus, the primary purpose of this study is to contribute in this research line through the analysis of statistical collected data.

This paper is part of an integral research of thermal comfort, in which thermal sensation and preference were simultaneously analyzed; in each case, a partial result set allowed to define thermal perception at an individual level. Nonetheless, in this publication, only thermal preference analysisresults areshown; which, for validity purposes, were evaluated applying Auliciems & Szokolay [1] mathematical equations, as well as thermal sensation values previously estimated by the author. The aims proposed for this study are enlisted as follows:

a) Neutral temperature (Tn)estimation on the basis of thermal preference analysis per study period: cold and warm.
b) Comfort range (ZC) on the basis of thermal preference analysis per study period.
c) Tn-ZC annual adjustment.

II. METHOD

The methodological procedure employed in this study is divided in seven sections:

1. Case of study andtarget population,
2. Study periods,
3. Design of statistical sample,
4. Design of survey questionnaire,
5. Data Logging Equipment,
6. Survey questionnaire application and
7. Data processing.

1.1. STUDYCASEAND TARGET POPULATION

Pachuca city is located in the state of Hidalgo, with geographical coordinates: 20°07'21" north latitude, 98° 44' 09" west longitude and 2,400 above sea level [7]. According to Garcia [8], itpresents a dry cold climatewith an arid semi-cold bioclimatic classification, based on Fuentes and Figueroa [9]. Itsannual mean dry-bulb temperature reaches (DBT) 14.3 °C andrelative humidity (RH) 62.6 %, average annual rainfallis 345.2 mm and North-eastprevailing winds with a speed oscillation between 3.9 m/s and 5.5 m/s [10].The target population observed to carry out the correlational studies were students of the Technological Institute of Pachuca (ITP), subjects on average age from 18 up to 23 years, residents of the above-cited city, with sedentary activity (1.2 met, in compliance with ISO 8996 [11]) and clothing insulation thermal resistance of 0.7 to 1.0 clo [3], depending on the period of analysis, warm or cold, respectively.

1.2. STUDY PERIODS

Periods considered to carry out the studies and the estimation of thermal comfort values were established according to the extreme thermal conditions of a typical year in the city of Pachuca [9]:

a) Warm season. Its maximum average, average and minimum average DBT correspond to 23.8 °C, 16.7 °C and 10.5 °C respectively; in turn, its maximum average, average and minimum average RH are 81.5%, 57.1% and 28.7%. The study of this period was carried out in May 2013

b) Cold season. Its maximum average, average and minimum average DBT correspond to 19.3 ° C, 11.6 ° C and 5.0 ° C respectively; Meanwhile, its maximum average, average and minimum average RH are 81.5%, 57.1% and 28.9%. The study of this period was carried out in January 2014

1.3. DESIGN OF STATISTICAL SAMPLE

Sample from which the correlational studies were carried out was designed with a confidence interval of 5.0% and a confidence level of 95.0%; in this way, the sample design corresponded to 348 observations per evaluation period. However, during the cold period, 364 observations were obtained and during the warm period 276 were collected, as can be seen in Table 1.

Table 1. Observationsprocessed duringstudy periods: warm and cold (gender classification)

Study period	Evaluation period		Observations		
	Month	Year	Obs.	*Female*	*Male*
Cold	January	2014	364	*125*	*239*
Warm	May	2013	276	*95*	*181*
			640	*220*	*420*

1.4. DESIGN OF SURVEY QUESTIONNAIRE

The measurement tool consisted of a survey questionnaire designed in seven sections and 42 questions. Thermal preference section was based on the seven-point subjective scale suggested in ISO 10551 [5], and was adapted as shown in Table 2.

Table 2. Thermal sensation used in survey questionnaire.

ISO 10551 scale (1995)	Modified scale	Thermal preference
+3	7	Much warmer
+2	6	Warmer
+1	5	A little warmer
0	4	Neither warmer, nor cooler
-1	3	Slightly cooler
-2	2	Cooler
-3	1	Much cooler

1.5. PHYSICAL FACTORS ANDDATA LOGGING EQUIPMENT.

Physical variables recorded simultaneously with the application of surveys were: Dry Bulb Temperature (DBT), Black Globe Temperature (T_G), Relative Humidity (RH) and Wind Speed (WS). In addition,clothing thermal insulation, metabolic activity and body mass index for each person surveyed were calculated.Weather features were measured and recorded with a Reed®, SD-2010 heat stress meter datalogger with 0.1 °C resolution in temperatures and 0.1% for RH; ± 0.8 °C DBT accuracy, ± 0.6 °C for T_G and ± 3% for RH. Also, the WS was measured and recorded with a Delta OHM® DO9847K anemometer whose resolution is 0.01 m/s and ±0.02 m/s accuracy (Fig. 1).Equipment selection and distribution was based on ISO 7726 [12] and ANSI/ASHRAE 55 [3] respectively, which allows to classify as class II databasethe obtained one in each evaluation [6].

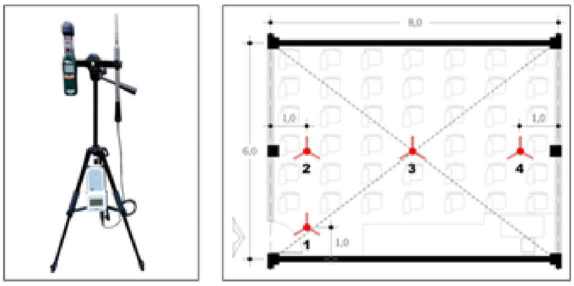

Figure 1. Left: datalogging equipment. Right: Equipment setting atclassroom as experimental scenario.

1.6. SURVEY QUESTIONNAIRE APPLICATION

The studies were conducted in classroom buildings (spaces where students spend most of their time) which show a typical state designed architectural typology built by what was formerly called CAPFCE, these spaces are naturally ventilated. The general procedure for conducting observations from questionnaires application was developed as follows:

a) Groups were deterministically selected based on:
   • Students must attend third semester or later (minimum stay of one year in the city of Pachuca).
   • The group should cover a mixed student population.
   • Groups should cover specific times (07 h 00-09 h 00 and 15 h 00-17 h 00) in order to attend the most critical cold and warm moments of a typical day.
b) Two groups of students were evaluated on a daily basis: morning/afternoon time shifts. The application startedafter 30 minutes of classbeginning.
c) At the beginning of each evaluation, data logging equipment was installed within the classroom -as suggested by ANSI / ASHRAE 55 [3] in terms of position and heights (Fig. 1) as well as the questionnaires to each participant.
d) During the evaluation, a coordinator read the questionnaire, solved doubts, recorded physical feature readings already mentioned and carried out the progress of the questionnaire (Fig. 2). Total evaluation time took 18 min approximately.
e) At the end of the questionnaire, weight and size were optionally measured (Fig. 2), these data should be stated on the report.
f) Finally, the questionnaires were collected neatly in order to define a survey serial number parameter.
   Based on this methodological procedure,14 groups in May (276 observations, TPR) and 17 groups in January (364 observations, TPR)it were possible to survey.

Figure 2. Left.On-site assessment application. Right: Measurement of height and weight.

1.7. DATA PROCESSING

Although DBT, T_G, RH and the WS were recorded simultaneously during the on-site survey application andincluding the emission of comfort votes, this paper only provides the results obtained from thermal preference (TP) and DBT correlation for each study period. For this, correlational data analysis were carried out via MIST method developed by Gómez *et al.* [13], which uses descriptive statistics (standard deviation, SD) in the estimation of a neutral temperature value (defined as comfort) and two ranges of thermal comfort (extended and reduced) that can result not equidistant to neutrality value. Data correlation was developed according to the three levels of activity (passive, moderate and intense), without distinction by gender, age or body size.

III. RESULTS

The results presented in this work are product of correlation between TP analysis and DBT exclusively for the warm and cold periods of the city of Pachuca, Hidalgo(Fig. 3 and Fig. 4, respectively). In this sense, the comfort votes collected during the warm period reflect a higher concentration in the TP cooler categories, as well as superior adaptation to temperatures below from that of Thermopreferendum (Fig. 3).For this period, comfort ranges are not equidistant to Tn, the lower limits represent greater distance than the upper limits, which allows to justify the cooling requirements manifested.

WARM PERIOD
Dry Bulb Temperature - Thermal Preference Analysis

SD	TP	Scale	-2 SD	-1 SD	Mean	+1 SD	+2 SD	TPR
0.5	A little warmer	5	19.0	19.5	**20.0**	20.5	21.0	28
2.7	Neither warmer nor	4	17.3	20.0	**22.6**	25.3	28.0	68
2.6	Slightly cooler	3	19.4	22.0	**24.6**	27.1	29.7	105
1.7	Cooler	2	23.0	24.7	**26.5**	28.2	29.9	63
2.5	Much cooler	1	22.2	24.7	**27.2**	29.7	32.2	12

	-2 SD	-1 SD	Mean	+1 SD	+2 SD
Equation	*y = -0.54x 13.95*	*y = -0.61x 16.42*	*y = -0.53x 15.77*	*y = -0.42x 14.00*	*y = -0.33x 12.34*
r^2	*0.6585*	*0.9203*	*0.9659*	*0.8981*	*0.8101*
Neutral	**18.3**	**20.5**	**22.3**	**23.8**	**25.1**
Limits	*-3.9*	*-1.7*		*1.5*	*2.9*

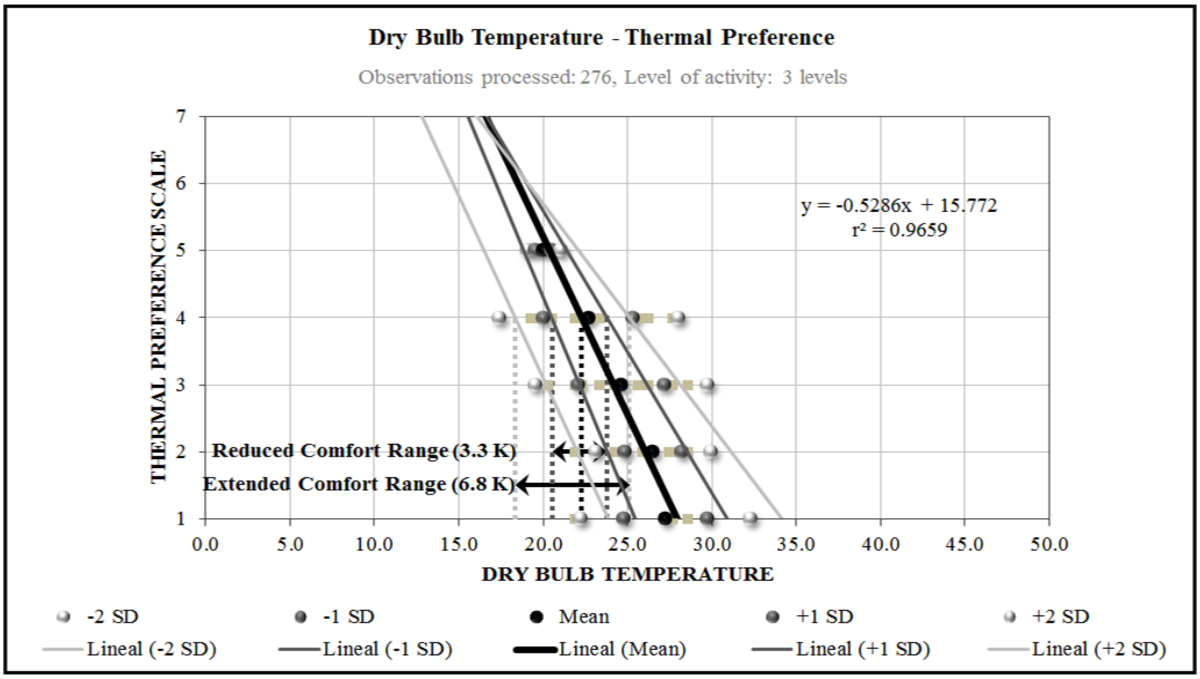

Figure3. Warm period DBT-PT correlation.

For this period, the Tn estimated from thermal preference results in 22.3 °C (r^2 = 0.9659), with a reduced thermal comfort range from 20.5 °C to 23.8 °C (3.3 K) and an extended temperature from 18.3 °C to 25.1 °C (6.8 K). However, the values obtained based on the TS-DBTcorrelation, object of another publication [14]but cited in this work as reference of comparison and validation of theestimated ones, show a Tn of 23.4 °C (r^2 = 0.9988) with a thermal comfort range reduced from 21.3 °C to 25.3 °C (4.0 K) and an extended from 19.1 °C to 26.9 °C (7.8 K).

Thus, the difference between both Tn values corresponds to 1.1 K; between the reduced ranges, to 0.7 K; and, between the extended ranges, to 1.0 K; In all cases, the values estimated based on TP are below those obtained with the TS, which allows us to see that during the warm period in the city of Pachuca there is a greater tendency for cold temperatures than for warm ones.

COLD PERIOD
Dry Bulb Temperature - Thermal Preference Analysis

SD	TP	Scale	-2 SD	-1 SD	Mean	+1 SD	+2 SD	TPR
1.9	A little warmer	5	13.2	15.1	**17.0**	18.9	20.8	126
3.9	Neither warmer no	4	12.9	16.8	**20.7**	24.6	28.5	101
3.1	Slightly cooler	3	17.8	20.9	**23.9**	27.0	30.0	89
1.3	Cooler	2	23.0	24.3	**25.6**	26.9	28.2	42

	-2 SD	-1 SD	Mean	+1 SD	+2 SD
Equation	*y = -0.25x 7.72*	*y = -0.31x 9.42*	*y = -0.34x 10.81*	*y = -0.30x 10.91*	*y = -0.23x 9.67*
r^2	0.8708	0.9766	0.9741	0.8018	0.5421
Neutral	**14.7**	**17.6**	**20.3**	**22.7**	**24.7**
Limits	-5.6	-2.7		2.4	4.4

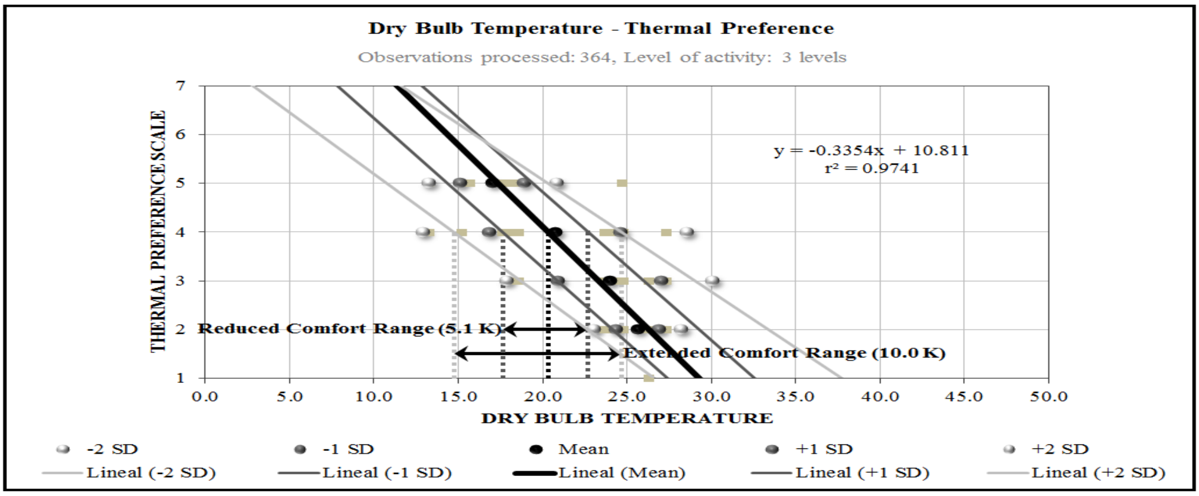

Figure4. Cold period DBT-PT correlation

On the other hand, the estimated Tn based on Auliciems and Szokolay model (1997) corresponds to 22.8 °C, which allows to infer that this temperature technically is in the middle between the values obtained with TP and TS analysisrespectively.Meanwhile, in the cold period, the comfort votes indicate again greater concentration in the cool TP categories (cooler to a little warmer), as well as a superior adaptation to temperatures below the Tn that above of this one (Fig. 4). For this period, the comfort ranges do not appear equidistant to the neutrality value, the lower limits represent greater distance than the upper limits. This makes reference to greater subject'sadaptation to semi-cold bioclimate show to temperatures below the neutrality than those above.

For the cold period, the estimated Tn from the thermal preference results in 20.3 °C (r^2 = 0.9741), with a reduced thermal comfort range from 17.6 °C to 22.7 °C (5.1 K) and an extended one from 14.7 °C to 24.7 °C (10.0 K). However, TS based values show a 21.4 °C Tn value (r^2 = 0.9763) with a reduced thermal comfort range from 19.4 °C to 23.4 °C (4.0 K) and an extended range from 17.3 °C to 25.4 °C (8.1 K). In this sense, the difference between both Tn corresponds to 1.1 K; between reduced ranges, to 1.1 K; and, between the extended ranges, to 1.9 K.In all cases, the values estimated based on the TP are below those obtained with TS analysis, which allows to infer that in this period again there is a greater tendency for temperatures below those of comfort than for those above this (Fig. 4).

On this regard, based on Auliciems and Szokolay (1997), Tn results in 21.2 °C, demonstrating a greater approximation with the ST obtained value (difference of 0.2 K) than with the estimated with TP (0.9 K). This allows us to observe that during the warm period the cold temperatures are more frequently accentuated than during the cold period, which is natural to assume due to the studied population sample, which is mostly familiar to semi-cold thermal conditions ofPachuca city.Table 3 concentrates the estimated Tn results and reduced and extended thermal comfort ranges per study period. In this matrix can be seen that thermal comfort ranges for the cold period are more extended than those obtained in warm period, which is equivalent to a greater acceptability of the cold thermal conditions than in the warm ones when observing that the difference between these ranges is accentuated towards the temperatures located below comfort than those located above it.

Table 3. Tn y ZC (reduced and extended) estimated for each period from thermal preference analysis

Study period	Neutral		$ZC_{reduced}$		$ZC_{extended}$	
	Tn (°C)	r^2	Limits (°C)	Range (K)	Limits (°C)	Range (K)
Warm	22.3	0.9659	20.5 - 23.8	3.3	18.3 - 25.1	6.8
Cold	20.3	0.9741	17.6 - 22.7	5.1	14.7 - 24.7	10.0

IV. CONCLUSIONS

Neutral temperature estimated from the existing correlationbetween TP-DBTfor extreme thermal periods of a typical year in the city ofPachuca cityare: 22.3 ° C in warm period and 20.3 °C for the cold period. The differences found between the Tnvalues and thermal comfort ranges estimated in parallel from the TP and TS allow us to conclude the variable conditions of the thermal environment to which the subject must adapt psycho-physiologically throughout the year.Estimated comfort range with the TP-DBTcorrelation for the cold period is wider than that obtained with the TS-DBT correlation (10.0 and 8.1 K, respectively); thermal comfort range estimated with the TP-DBT correlation for the warm period is narrower than that obtained withTS-DBT correlation (6.8 and 7.8 K, respectively). The above suggests that, since thermal comfort estimated from the TS shows the degree of tolerance that people present with respect to environmental thermal conditions, the estimate based on the TP refers to the ideal thermal conditions desired by the subjects. In the latter case, due to the adaptive effect to the critical conditions of Pachucacity, the resulting values showed a higher tendency to temperatures lower than the Tn than the higher values of Tn in each study period. Based on Auliciems and Szokolay model (1997), which depends on the average external temperature to obtain the comfort temperature, a Tn of 21.2 °C was estimated for cold period and one Tn of 22.8 °C for warm period. The approximation between these results and those obtained with this study allows to prove that, in naturally ventilated buildings (classrooms), Tn value is an external average temperature function, as Humphreys (1981) pointed out.In compliance with this, the phenotypic adaptation of the subjects in semi-cold bioclimate is a result of prolonged exposure to low temperatures throughout the year, which produces greater tolerance amplitude and preference compared to temperatures below Tn; in contrast, the subject reduces its thermal adaptive ability in environments with temperatures above the Tn.

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