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Neutral Temperature in Outdoors for Warm and Cold Periods for Extreme Warm Dry Climate

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ABSTRACT

To generate design proposals that favor thermal comfort of the users is necessary to estimate the neutral temperature and ranges of thermal comfort in outdoors. A study of thermal comfort of an outdoor recreational space, in warm and cold periods in a desert climate, is presented. A questionnaire based on ISO 10551 was designed. Dry bulb temperatures, gray globe temperatures, relative humidity and wind speed were measured. 822 surveys were applied to the warm period and 863 to the cold period. Neutral temperature and ranges of comfort with the method of averages by thermal sensation interval's, were estimated. Passive, moderate and intense activities were analyzed. The periods studied showed a behavior of asymmetric climate. Neutral temperatures are approximately symmetrical with respect to their range of thermal comfort. Persons subject to intense activity have better adaptation to climate.

Keywords: Thermal comfort, Neutral temperature, Adaptive method, Outdoor spaces, Extreme warm dry climate.

1. INTRODUCTION

Perceived thermal sensation by the individuals in the outdoors cannot be fully explained by the human body's energy balance (Lin *et al.,* 2011). This is due to thermal adaptation includes (in addition to acclimatization) the effects of psychological aspects and the thermal environment (Nikolopoulou and Steemers, 2003). To set the foundation for sound decision making in the design of spaces must know the temperatures of thermal comfort outdoors, which can lead users to be in thermal comfort to carry out their activities properly.

The time spent in outdoor spaces, are less than the interior, due to thermal adaptation process, which generates the application of a model developed for indoors thermal comfort has a tendency to overestimate the actual sensation of the outdoors user. This discrepancy is greatest in low temperature conditions compared to high temperatures.

Outdoors, the use of a predictive model for the implications of variability of thermal environments, outdoor conditions and residence times, is not suitable, while the application of adaptive method, because is the result of an evaluation field is best suited to outdoor conditions (Höppe, 2002).

The need for research on perceived thermal sensation outdoors, has been seen in events like Olympics and world fairs (Pickup and deDear, 2000), and projects such as Rediscovering the Urban Realm and Open Spaces (Nikolopoulou, 2004), contributions of this work have applications in projects such as tourism, recreational or exhibition areas.

Lin (2009) and Lin *et al.*, (2011) developed a preference study on thermal sensation in the outdoors for hot and cold periods in a warm humid climate. The new standard effective temperature (SET*) was used as a reference model. The results demonstrated the adaptation of subjects to study periods and the effect of meteorological variables.

In another phase of that study, Hwang and Lin (2007) analyzed the thermal comfort conditions in outdoors and semi-outdoors, and showed how individuals lower their expectations of thermal comfort in rooms with these characteristics, and thereby increasing their tolerance to uncomfortable conditions.

Spagnolo and deDear (2003) developed a comparative study of thermal comfort conditions in outdoors and semi-outdoors in subtropical climate. Results were compared with rates OUT-SET* and SET*. It was shown that the values of outdoor thermal comfort are significantly higher than indoor values. According to these authors the studies of outdoor thermal comfort in outdoors and semi-outdoors fall into three subcategories as a final goal, which are: 1) Modification of the thermal environment to reduce its impact on users, 2) Weather and tourism, and 3) Thermal comfort of pedestrians.

The study by Oliveira and Andrade (2007), overall performance was similar to Spangolo and deDear (2003). It also established the importance of wind effects on the thermal sensation perceived.

In the investigations mentioned, studies were developed based on passive activity individuals, in spaces like parks, railway stations, bus stops and public squares. While in this work, the aim is to present the estimation of thermal comfort temperatures of individuals in passive, moderate and intense activity in outdoor spaces of a recreation center, in warm and cold periods of a desert climate.

The study was conducted with a focus on adaptation of thermal comfort by applying scale surveys with ISO 10551:1995 of perceived sensations, with the simultaneous use of instruments that record data from dry bulb temperature, relative humidity, wind speed and gray globe temperature. Later, there was a statistical analysis by stratum of perceived thermal sensation and performed a linear regression of the data collected to obtain the temperatures and thermal comfort limits by levels of activity: passive, moderate and intense.

The periods analyzed showed an asymmetric behavior of climate. Overall arguably neutral temperature values are approximately symmetrical with respect to its extensive and adjusted ranges of thermal comfort. The values obtained of neutral temperature in critical periods of heat and cold, prove the theory of adaptation, as the subjects of intense activity, with regular practice of exercise and proper habits to weather conditions (dress and fluids), have a temperature of thermal comfort similar to those with passive activity.

2. METHOD

The adaptive parameters of the approach used were: data source, type of habitat, reactions to analyze, type of receiver of the information and level of analysis. For the selection of the approach of this study also other similar works were also reviewed (Nikolopoulou, 2004; Höppe, 2002; Givoni *et al*., 2003; Lin (2009); Lin *et al.,* 2011; Hwang and Lin, 2007; Spagnolo and deDear, 2003; Oliveira and Andrade, 2007).

The study was realized in Mexicali, Baja California, a city of the northwest of México, that is situated at latitude of 32°39'54" N, longitude of 115°27'21" W, and an altitude of four meters above sea level. The climate is warm and extremely dry, with an average maximum temperature of 42ºC (with extreme maximum of 52ºC) and an average minimum temperature of 8°C (with extreme minimum of -6ºC) (Luna *et al.*, 2008). In figure 1, appears Mexicali's location.

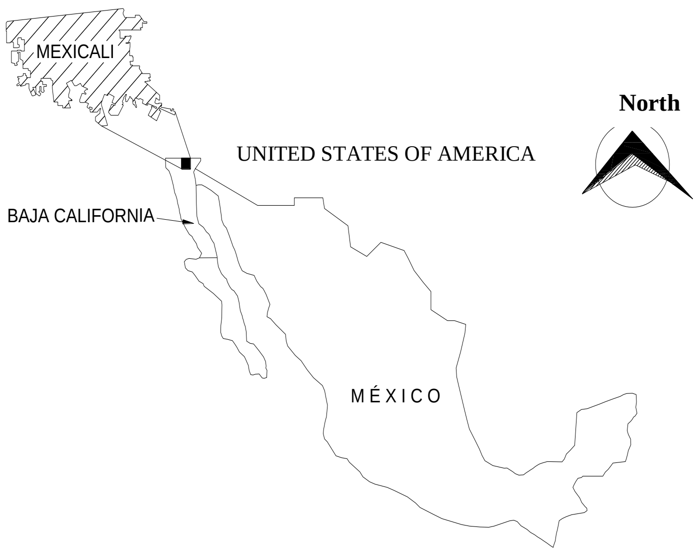


Figure 1: Location of Mexicali, Baja California, México

The research was carried out in the YOUTH RECREATION CENTER 2000, where sports, outdoor exercises and other living activities are practiced. This park presents green areas, corridors of concrete and land, sports fields of basketball, soccer, baseball and track to trot, as some administration buildings, gymnasium and area of special courses (See figure 2).

Figure 2: Youth Recreation Center 2000

A correlation study of dry bulb temperature with the thermal sensation perceived was developed. The periods studied are presented in table 1. The schedules of application of survey were from 07:00 to 21.30.

Table 1: Periods of study of fieldworks

PERIOD TYPE	PERIODS OF STUDY
Warm	July 25th to August 10th, 2008
Cold	2nd to the 20th of January, 2009

Three activity levels were analyzed: 1) Passive (0 to 75 W/m^2), 2) Moderate (76-183 W/m^2) and 3) Intense (183-600 W/m^2). The metabolic rate was estimated based on the similarity of activities (running, soccer, basketball, parkour, cycling, skating) in the study area, regarding the list presented by ISO 8996 (2005) in its table of specific activities.

Passive type activities were: walking, observing, talking and playing with children in a calm manner. The type of moderate activities were jogging, light exercise and playing interactively with children, while intense activities were running, intense exercise, playing soccer, basketball and baseball as well as bicycle stunts, skateboarding and parkour.

The clothing insulation level was estimated based on a classification of the type of clothing (five scales, from very light to very clothed), and determined the average level of clothing by sex of individuals and scale of clothing, according to the values found ISO 9920 (2009). The levels of average clothing (Clo) of subjects studied by period are presented in table 2.

Table 2: Clo average of people for period and activity level

Period of study	Clo average Pasive activity	Clo average Moderate activity	Clo average Intense activity	Clo average for period
Warm	0.40	0.37	0.33	0.36
Cold	0.82	0.81	0.69	0.77

The selection of climate variables to measure are based on the effect of them on the perceived thermal sensation, as well as analysis of some case studies on thermal comfort indoors and out (Oliveira and Andrade 2007, Hwang and Lin, 2007; Nikolopoulou, 2004; Spagnolo and deDear, 2003, Pickup and deDear, 2000; deDear *et al.*, 1998; Potter and deDear, 2000, Lin (2009); Lin *et al.*, 2011) and ISO 7730 (2005), ISO 7726 (1998) and ISO 10551 (1995).

The variables of measurements were: dry bulb temperature, relative humidity, wind speed and gray globe temperature. Also a thermal stress equipment was utilized. (See figure 3). As the methodology the equipment met the majority of the requirements of the norm ISO 7726 (1998), reason why the generated data are of Class II (Brager and deDear, 1998).

The questionnaire was designed based on ISO 10551 (1995) and a manual of application of survey and manual of instruments were developed. A sample with a reliability of 95% and precision of the estimators of 5% was designed. 380 observations were estimated, but due to the acceptance of the study among respondents were reached a total of 822 applications in the warm period and 863 applications in the cold period.

Figure 3: Monitor of thermal stress

The process of selection of subjects was of a deterministic type. The study subjects were men and women between 12 and 65 years of age, did not include individuals with irregular biological conditions like chronic diseases or pregnancy. An image of application of surveys appear in figure 4.

Figure 4: Application of surveys

The data analysis was carried out with the method of “Averages of Thermal Sensation Interval” (ATSI) (Gómez Azpeitia *et al.*, (2007), which was developed based on the proposal of Nicol (1993) for “asymmetric” climates. A scheme of the mentioned method appears in figure 5.

The fundamental difference of the ATSI with the conventional method is that obtaining the line of regression that characterizes the studied sample, groups or stratum of the same are determined to calculate the value average and the standard deviation (SD) of each of them.

Thus, the regression is not done with all the pairs of data of the sample, but is determined only with the average values and ranges are determined by the addition and subtraction of one or two times the standard deviation of the sample.

The purpose of this procedure is to determine the average value of temperature of all the responses of each level of perceived thermal sensation. In that manner it was calculated the average temperature of the individuals that reported feeling comfort, but also of those who expressed other thermal sensations.

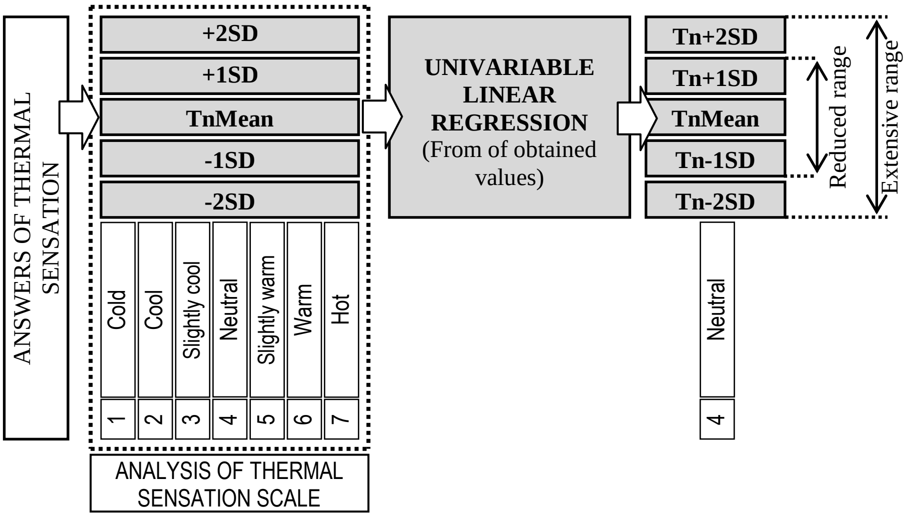


Figure 5: Method of Averages of Thermal Sensation Interval (ATSI)

Based on the above, the data collected in the field study was processed separately according to each of the seven categories of comfort response of ISO 10551 (1995). The values were determined for each of them and the average and standard deviation of the temperatures registered for each collected answer. When the number of answers for a certain group was not sufficient to obtain reliable results, the procedure was omitted and the category was eliminated.

Once this data was obtained, ranges of distribution were established for each category of response. It was made from the average value of corresponding temperature (TnMean) and the addition of ±1SD, the procedure is repeated and is added ±2SD to the TnMean.

Finally a linear regression was made with the values that were obtained, to determine the corresponding lines to the extensive limits of the range defined by TnMean ±2SD, and the reduced limits defined by TnMean ±1SD.

Also the same was done with the values of TnMean. In that way graphs are obtained for every period of the study. The intersection of each one of the lines of regression with the ordinate four (that represents the thermal sensation of comfort) determines the value of the neutral temperature according to ATSI method, as well as, the limit values of the ranges of thermal comfort.

3. RESULTS

The results are presented in a specific form by period and activity level, and then a comparative analysis is made.

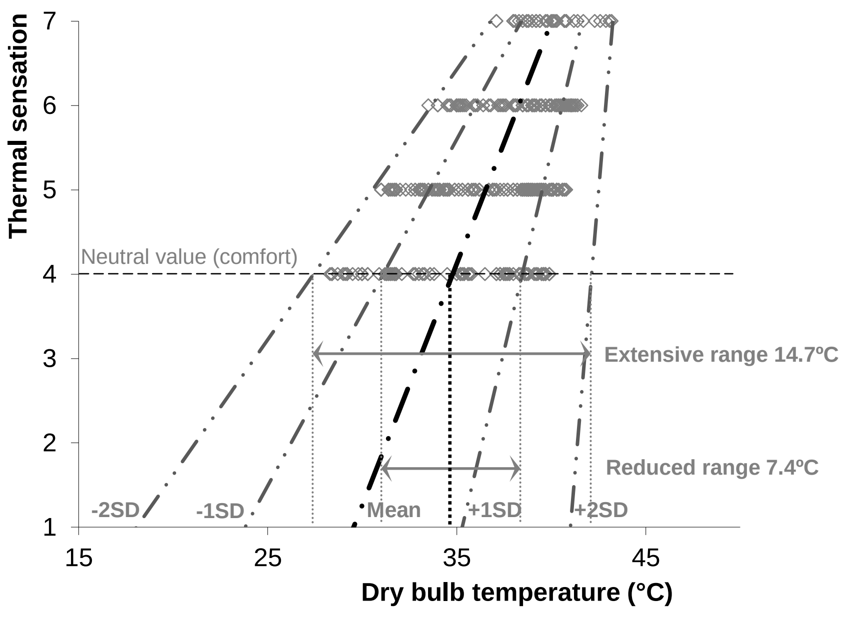
Warm period

The passive activity in the warm period had 389 observations. In this case there were no sensations of cold (3 to 1); moreover, according to the lines of regression it showed a trend of increased of thermal adaptation to the sensations of warm (5 to 7). The above described is shown in Figure 6a. The neutral temperature of passive activity was symmetric with respect to extensive and reduced thermal comfort ranges. This is due to low internal energy generated and thermodynamic exchange with the thermal environment.

Moderate activity in the warm period, consisted of 257 observations. There were no sensations of cold (3 to 1), but according to the lines of regression it shows a similar thermal adaptation to both the sensations of cold and warm. The neutral temperature was slightly asymmetric with respect to thermal comfort ranges extensive and reduced. Worth mentioning that in this level of activity there was greater variability in the internal energy due to the different activities taking place in this activity level. The above described is shown in Figure 6b.

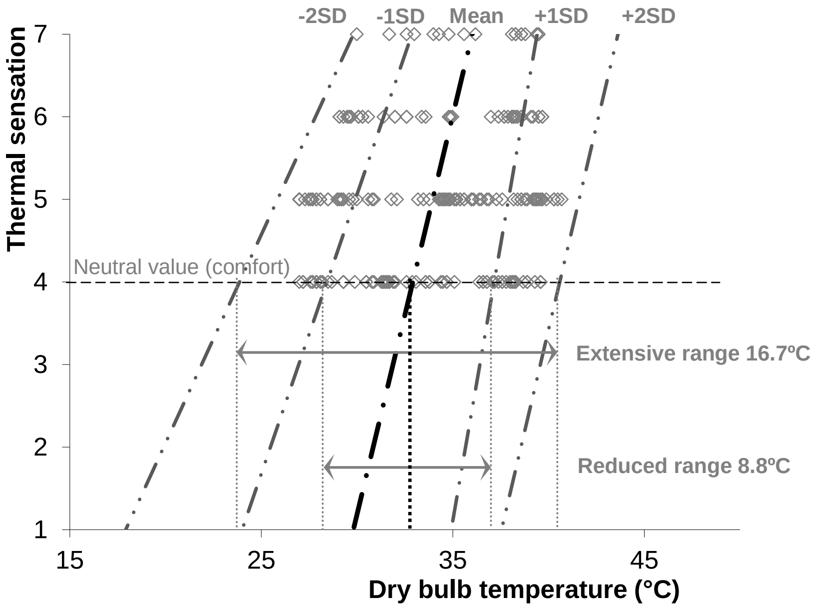
The intense activity in the warm period consisted of 177 observations. There were no sensations of cold (3 to 1), but according to the lines of regression it shows a similar thermal adaptation to both the sensations of cold and warm. The neutral temperature was symmetrical with respect to thermal comfort ranges extensive and reduced.

Worth mentioning is that in this level of activity there was a greater degree of alignment due to the frequency of practiced activities, and psychological adjustment (expectation and experience, reactive behavior) so that its temperature of thermal comfort is similar to that of subjects with passive activity. The above described is shown in figure 6c.



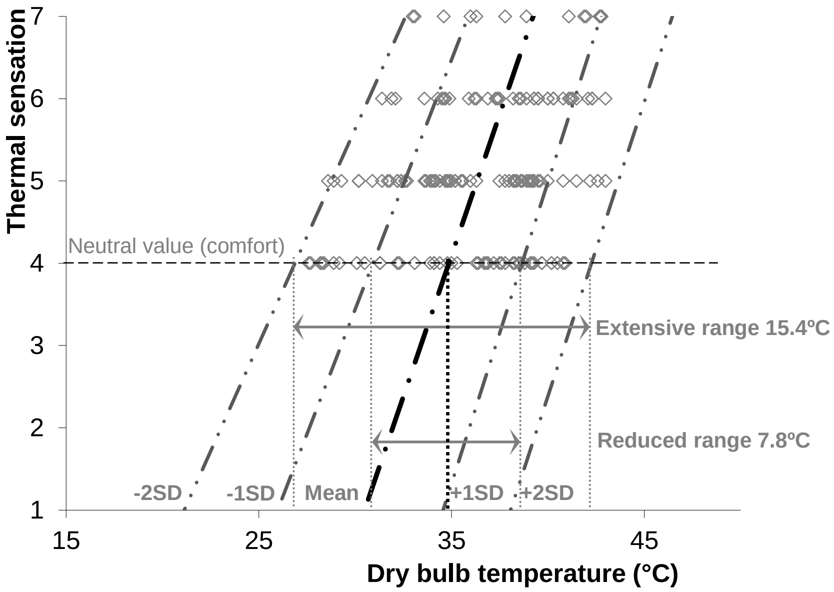
Tn-2SD	Tn-1SD	**TnMean**	Tn+1SD	Tn+2SD
27.4°C	31.1°C	**34.8°C**	38.5°C	42.1°C

a) Passive activity



Tn-2SD	Tn-1SD	**TnMean**	Tn+1SD	Tn+2SD
23.9°C	28.4°C	**32.9°C**	37.2°C	40.6°C

b) Moderate activity



Tn-2SD	Tn-1SD	**TnMean**	Tn+1SD	Tn+2SD
26.9°C	30.9°C	**34.9°C**	38.7°C	42.3°C

c) Intense activity

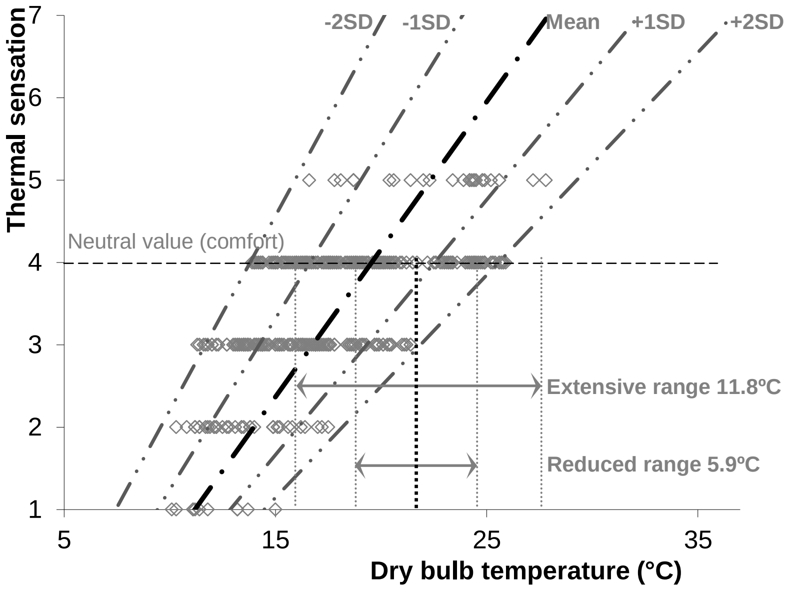
Figure 6: Neutral temperature and thermal comfort ranges in warm period

Cold period

The passive activity in the cold period had 449 observations. In this case beside the feelings of cold, there were “slightly warm”, this is due to the internal temperature from metabolic activity and levels of clothing. Based on the regression lines is showed a trend of greater adaptation to thermal sensations of cold (1 to 3). The neutral temperature was symmetrical with respect to extensive and reduced ranges of thermal comfort. The above described is shown in figure 7a.

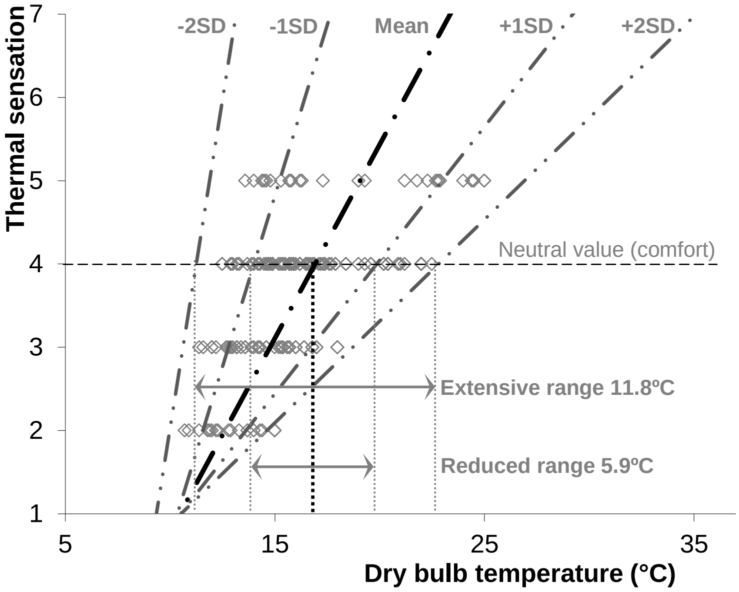
Moderate activity in the cold period, consisted of 219 observations. In addition to the cold sensations (1 to 3) were presented feelings of “slightly warm”. Based on the regression of lines it shows significant thermal adaptation to cold conditions. The neutral temperature was symmetrical with respect to thermal comfort ranges. Note that in this level of activity there was greater variability in the internal energy due to the different activities taking place in this range, as well as varying levels of clothing. The above described is shown in Figure 7b.

The intense activity in the cold period consisted of 195 observations. In addition to the cold sensations (1 to 3), it presented feelings of “slightly warm” and “warm”. Based on the regression lines it shows an increased thermal adaptation to cold sensations, this is due to temperature levels generated by high metabolic activity. The neutral temperature was symmetrical with respect to thermal comfort ranges extensive and reduced. The above described is shown in figure 7c. It is worth noting that in this level of activity a greater level of thermal adaptation was presented due to the frequency of practiced activities, as well as the psychological adaptation.



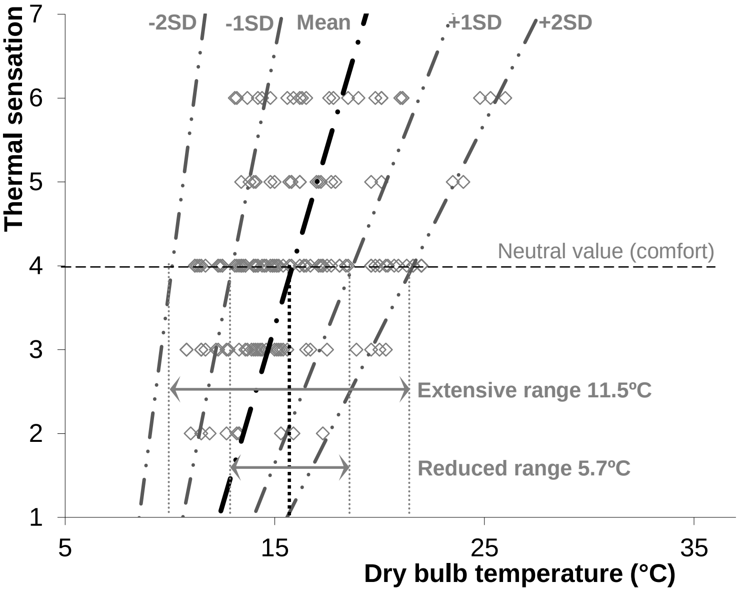
Tn-2SD	Tn-1SD	**TnMean**	Tn+1SD	Tn+2SD
13.8°C	16.6°C	**19.6°C**	22.5°C	25.6°C

a) Passive activity



Tn-2SD	Tn-1SD	**TnMean**	Tn+1SD	Tn+2SD
11.2°C	14.0°C	**16.9°C**	19.9°C	22.8°C

b) Moderate activity



Tn-2SD	Tn-1SD	**TnMean**	Tn+1SD	Tn+2SD
10.1°C	13.0°C	**15.9°C**	18.7°C	21.6°C

c) Intense activity

Figure 7: Neutral temperature and thermal comfort ranges in cold period

Comparative analysis

This section provides a comparative analysis of results by period and activity level. The aspects studied were the neutral valu**e** (Tn: comfort temperature), thermal comfort ranges and coefficient of determination.

In the warm period it was observed that no proportional variation between the level of activity and the increase or decrease values of Tn, whereas in the cold period there is this relationship with respect to a reduction in Tn, with increasing activity level. The above described is shown in table 3.

There was a significant variation in the neutral temperature of a warm period to a cold period; this is due to the adaptation process of the subjects based on the thermal environment conditions.

In regard to thermal comfort ranges, their behavior was similar to those of Tn, in both periods. The wider range is presented in subjects with moderate activities, this shows that subjects in this level of activity are less suitable thermally as it coincides to a neutral value lower than the other levels of activity with wider ranges.

Values of the coefficient of determination (R^2) in both study periods had values between 0.9353 and 0.9999, so the amount of variation in "y" significantly is explained by the regression of the data analyzed.

Table 3: Neutral values and ranges of thermal comfort for period and activity level

CHARACTERISTIC	PASSIVE ACTIVITY	MODERATE ACTIVITY	INTENSE ACTIVITY
	WARM PERIOD		
DBTn+2SD	42.2	41.0	43.4
DBTn+1SD	38.5	37.0	39.3
DBTn Mean	34.8	33.1	35.2
DBTn-1SD	31.1	29.1	31.2
DBTn-2SD	27.4	25.2	27.1
Extensive range	14.7	16.7	15.4
Reduced range	7.4	8.8	7.8
R^2 (MRL)	0.9999	0.9722	0.9353
CHARACTERISTIC	COLD PERIOD		
DBTn+2SD	26.4	21.8	22.3
DBTn+1SD	22.9	19.2	19.2
DBTnMean	19.3	16.6	16.0
DBTn-1SD	15.7	14.1	12.9
DBTn-2SD	12.2	11.5	9.8
Extensive range	11.8	11.6	11.5
Reduced range	5.9	5.9	5.7
R^2 (MRL)	0.9806	0.9843	0.9955

DBTn: Dry Bulb Temperature Neutral, SD: Standard Deviation, R^2(MRL): Coefficient of determination of Mean Regression Line.

4. CONCLUSIONS

The periods analyzed showed an asymmetric behavior of weather due to extreme cold or warm. The thermal comfort temperature presented a significant variation between the two periods extremes studied. The phenomenon of adaptation is clearly observed in changes in the value of Tn for each study period, which is similar to that shown by Lin (2009) and Lin *et al.*, (2011).

It may be assumed that as increases the metabolic activity, decreases the thermal comfort temperature if happens in the cold period; however, in the warm period, people with vigorous activities are better suited than those of moderate activity, addition to the type of clothing that use has less insulation, so that its thermal comfort temperature is similar to that of subjects with activity passive. This proves the claims of Humphreys and Nicol (2002).

Variation in thermal comfort temperature between one activity level and another was observed. This was due to the difference in clothing levels, frequency of activity and thermal and psychological adaptation of the subjects.

The major adaptive changes occur in the intense activity, while the less significant are given in the passive activity, due to physical condition and expectation and experience of people. The greatest variation in thermal sensations appeared in moderate activity, due to the different ranges of activities and their overall metabolism.

The variability in the symmetry and asymmetry of the trend lines in all three levels of activity is due to the diversity of levels of acclimatization and reactive and interactive behavior of the same.

In the case of thermal comfort ranges, the larger extensive range occurs in moderate activity, with similarity to passive activities, while the less wide is presented in intense activities. The adjusted range has its lowest in strenuous activity, with little variation in the other two levels of activity. This was due to the adaptation level of subjects by activity level. Based on the variation of amplitude of large and small ranges, there was a better adaptation to the cold period.

Although the thermal environment conditions showed variation when changing from warm to cold period, the effect of thermal acclimation and psychological adjustment was observed, as well as the experience and expectation.

The study serves as an aid in making design decisions for outdoors in desert climate, and to estimate the thermal comfort conditions of the users in two different bioclimatic periods for three levels of activity. Some possible applications of the results are: urban planning, urban design of bicycle paths, football stadiums, facilities for sporting events, extreme sports, marathon and triathlon routes, among others.

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