DOI number: 10.5027/jnrd.v7i0.12

JOURNAL OF NATURAL RESOURCES AND DEVELOPMENT

Research article

Adaptive Thermal Comfort in Learning Spaces: A Study of the Cold Period in Ensenada, Baja California

Julio Rincón[1*], Gonzalo Bojórquez[2] , Víctor Fuentes[3], Claudia Calderón[1]

[1] Facultad de Ingeniería, Arquitectura y Diseño, Universidad Autónoma de Baja California, Ensenada, B. C., 22860, México
[2] Facultad de Arquitectura y Diseño, Universidad Autónoma de Baja California, Mexicali, B. C., 21280, México
[3] División de Ciencias y Artes para el Diseño, Universidad Autónoma Metropolitana, Ciudad de México, 02200, México

* Corresponding author: julio.rincon@uabc.edu.mx

Article history

Received 25/09/2017
Accepted 13/12/2017
Published 24/12/2017

Keywords

Adaptive approach
Adaptive thermal comfort
Dry temperate bioclimate
Thermal environment
Thermal perception
Thermal sensation

Abstract

Environmental thermal conditions decisively influence people's performance, comfort, well-being and mood. In closed spaces, where people spend 80 % of their time, thermal perception is a phenomenon studied from a multidisciplinary methodological approach. In Mexico, thermal comfort has been studied in isolation in different cities in the country, specifically at sites with warm, temperate or semi-cold bioclimate. The thermal estimates presented in this paper are the result of a thermal comfort study carried out during the cold period in the city of Ensenada, Baja California, which has a dry temperate bioclimate. The study was carried out from January 30th to March 3rd 2017 and consisted of the application of a questionnaire and the simultaneous recording of temperature, relative humidity and wind speed. The questionnaire was designed based on the subjective assessment scale suggested in ISO 10551 and ANSI/ASHRAE 55, while the instruments for measuring and recording environmental variables were selected and used based on ISO 7726. A database with 983 observations was created, and the data were processed using the Averages Intervals Thermal Sensation method. The thermal comfort range estimated for indoor spaces was 16.8 °C to 23.8 °C, with an ideal neutral temperature of 20.3 °C. The percentage of satisfaction vote with these results was 91 %.

1. Introduction

The environment-human relationship has historically been studied in order to identify the effects that this implies on the health and the daily activities of humans. It is known that the atmospheric conditions on certain days stimulate people to carry out the activities; however, there are others days that repress the physical and mental efforts to realize them. In places that have extreme climatic conditions of warm or cold, the energy consumption required to achieve adaptation to the environment is greater **[1]**.

Thermal adaptation is "*the response's gradual decrease of the organism to repeated exposures of stimuli received from a specific environment*" **[2]**. In this sense, the sensation of thermal comfort is the result of the degree of adaptation that people manifest in relation to the conditions of the immediate thermal environment. Considering that people spend 80 % of their time in indoors spaces, the study of thermal comfort is important **[3]**.

The parameters that make up a habitable space's thermal environment are meteorological, physiological, spatial (architectural or natural) and circumstantial type **[4]**. Air temperature, radiant temperature, relative humidity and wind speed are some of the parameters considered in the first classification and are the primary factors that influence mainly the thermal sensation people feel **[5]**.

According to the adaptive approach, human thermal comfort depends on outdoor average temperature, time of permanence, level of activity and actions done to achieve it **[6]**. This phenomenon is a fundamental component in the habitability of architectural spaces and it can be understood as a condition that allows greater satisfaction and efficiency of the occupants in a building.

Over time, the human body has acquired relatively broad adaptability due to variations in the environment, so it can be exposed to extreme thermal conditions without protection and for short periods of time without suffering any damage. However, if the exposure to these conditions is prolonged, the organism shows certain disorders (stress, for example) and, as a result, its performance begins to deteriorate, with the risk of suffering lasting or irreparable damage to health (cardiovascular problems, nervous pathologies, respiratory diseases, to mention a few) **[7]**. For this reason, it has been observed that thermal comfort conditions contribute to establishing good interpersonal relations, higher productivity, good health and even to encourage creativity **[7]**.

Human behavior is a determining factor in the search for and acquisition of thermal comfort. If there is a change in the environment causing discomfort, people instinctively react in order to restore the comfort conditions **[8]**. Neutral Temperature (Tn), or comfort temperature, is obtained from a linear regression analysis that correlates the responses given by people in a field study (subjective records) and measurements of environmental parameters measured with instruments (objective records). Based on the latter, the dependence of neutral temperature on outdoor average temperature has been found, a relationship that is most significantly visualized in naturally ventilated buildings **[9]**.

In Mexico, different studies into thermal comfort have been carried out, among which is a study of six cities with a warm climate, where the thermal comfort in low-cost housing was estimated based on surveys **[10]**. There is also research into the implications of thermal comfort and energy saving from simulations and survey applications **[11]**. Likewise, there is another study into adaptive models for the different climates within Mexico from analysis of surveys by region **[12]**. These studies have concluded that Mexican's thermal comfort in hot climates is higher than the values established by international standards.

Thus, the results presented in this paper are part of an integral research project on thermal comfort carried out from the adaptive approach during the four representative thermal periods in the city of Ensenada, Baja California. This publication shows only the values estimated from the study carried out during the cold period. The objectives for this content are to:

- Present the estimated values for Tn and thermal comfort ranges.
- Describe the methodology applied in the study based on the adaptive approach.

2. Methodology

The methodological procedure that was applied in this study and that attends both the adaptive approach bases and international standards specialized in the thermal comfort phenomenon **[5] [13]** -**[17]** was classified in the following seven sections.

2.1. Study case and target population

Ensenada is located in the state of Baja California, México, with geographical coordinates: 31° 52′ latitude north, 116° 37′ longitude west and 1 to 1,900 meters above sea level **[18]**, 90 km south of the USA border and on the northwest coast of Baja California (Pacific Ocean) (**Figure 1**).

Based on its climatic conditions and geographical location, it has an extremely dry climate **[19]** and a dry tempered bioclimatic **[20]**. In a typical year the annual mean temperature is 17.1 °C, relative humidity is 80.8 %, average annual rainfall is 246.7 mm and it has north-west to south-west prevailing winds with a mean speed of 3.9 m/s. Although relative humidity is high throughout the year due to the proximity to the sea, rainfall is low and for a short annual period, meaning that its climatic and bioclimatic classification is dry **[21]**.

Ensenada has a population of 520,000 inhabitants, of them, according to the demographic pyramid of ages; the gross population is concentrated in ages between 15 and 19 years and between 20 and 24 years **[22]**. In regular conditions, it is common to find this population segment in meeting points such as university education centers.

For the above, the target population used to carry out the study was the student community of Autonomous University of Baja California, subjects on average aged from 18 up to 23 years, residents of Ensenada (native citizens or with at least one year of residence in the city), with sedentary activity (1.2 met) **[16]** and a mean thermal resistance by clothing insulation of 1.2 clo **[5]** in this thermal period.

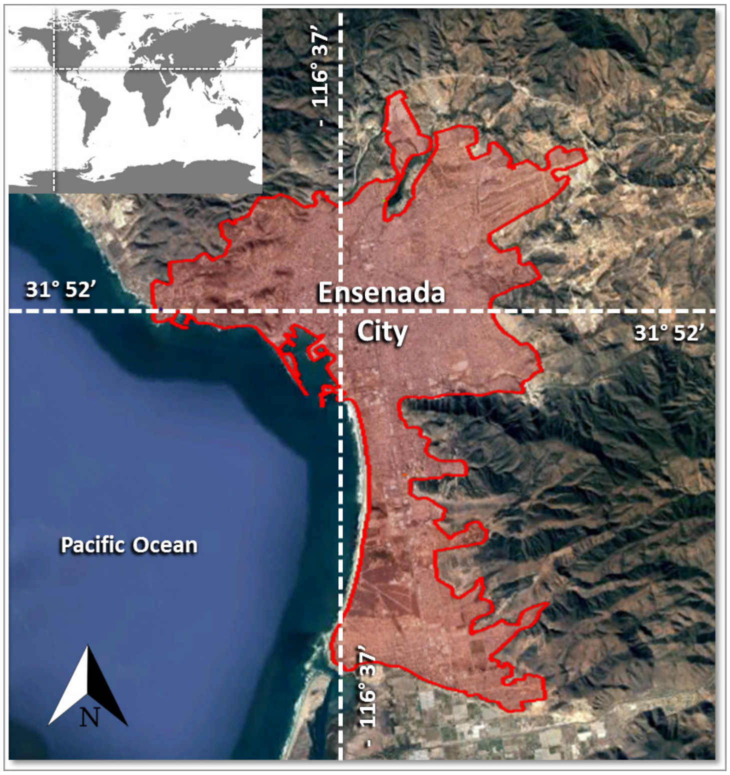


Figure 1: Geographical location and urban polygon of Ensenada.

2.2. Study period

The criteria considered to establish the period to carry out the thermal comfort study were a typical year's minimum thermal conditions in the city: Cold period. With the above, the study was carried out from January 30th to March 3rd, 2017.

The city has average temperaturesof 19.2 °C, 14.2 °C and 9.2 °C respectively, with average relative humidity (maximum, medium and minimum) of 89.5 %, 70.7 % and 46.2 % **[21]**. In Ensenada, the periods that indicate a typical year's extreme thermal conditions are: cold (February), warm (August) and the two transitions (May and November).

2.3. Design of statistical sample

The sample from which the study was 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 383 observations. However, it was possible to collect 983 total observations, of which 917 had the degree of certainty necessary to perform data processing (458 women and 457 men).

2.4. Design of survey questionnaire

The database was comprised of the total number of responses given by the people evaluated during the field study. To do this, the instrument used to collect the data and responses of each evaluation was a questionnaire designed with six sections and 35 questions (in **Appendix 1**), it was based on the ANSI/ASHRAE 55 standard questionnaire **[5]** and it was adapted to the local conditions of the city (linguistic regionalism) and the general objectives of the full study (environmental perception). The sections considered were:

A Control data.
B Participant information.
C Evaluation space information.
D Indoor environment sensation.
E Indoor environment preferences.
F Additional information.

Sections and questions related to thermal sensation were based on the seven-point subjective scale suggested in international standards specialized in thermal comfort **[5], [14]** (**Figure 2**), and its identification nomenclature was adapted as shown in **Table 1**.

Table 1: Thermal sensation scale used in this study

Thermal sensation	ISO 10551 scale	Adapted scale for this study
Hot	3	7
Warm	2	6
Slightly warm	1	5
Neutral	0	4
Slightly cool	-1	3
Cool	-2	2
Cold	-3	1

D. Indoor environment sensation
* Responses in this section should correspond with the indoor environment **SENSATION** that you perceive **right now**

20. How are now you feeling the temperature inside this architectural space? *(thermal sensation)*

1) Cold	**2)** Cool	**3)** Slightly cool	**4)** Neutral	**5)** Slightly warm	**6)** Warm	**7)** Hot
Pain in the extremities, requires thick clothing	Requires warm coat and / or warm drinks	Occasional discomfort resolved by direct exposure to the morning sun	Undiscovered thermal sensation, activities performed efficiently	Person with thirst, environmental conditions do not prevent activities	You regularly sweat, you require cold drinks	Nothing can refresh you, you sweat abundantly

Figure 2: Question from which the thermal sensation response of the people evaluated in field study was collected.

2.5. Physical variables and data logging equipment

Physical variables logged simultaneously with the application of the surveys were: Dry Bulb Temperature (DBT), Black Globe Temperature (TG), Relative Humidity (RH) and Wind Speed (WS). In addition, clothing thermal insulation, metabolic activity and body mass index for each person surveyed were calculated.

Environmental variables were measured and logged with a Reed® SD-2010 heat stress meter DataLogger. This instrument presents 0.1 °C resolution for temperatures and 0.1 % for RH; likewise, it has ± 0.8 °C accuracy for DBT, ± 0.6 °C for TG and ± 3 % for RH. The WS was measured and logged with a Extech AN10 anemometer whose resolution is 0.1 m/s and ± (3 % + 0.3 m/s) accuracy.

The measurement instruments were selected and distributed based on international standards specialized in thermal environment [5] [15]. These standards recommend the heights at which the measurement instruments should be located (assessments with people sitting): 0.10 m (ankle level), 0.60 m (abdomen level) and 1.10 m (head level) (Figure 3). Likewise, they provide the possibility of placing the measurement instruments at a geometric center of the evaluation space when resources permit it (Figure 4). Based on the above and considering that the evaluation spaces were classrooms (people sitting), laboratories and drawing workshops (semi-seated people), it was possible to adapt the measuring instruments heights to 0.10 m, 0.85 m and 1.40 m in architectural spaces with semi-seated people (Figure 3).

The above mentioned, allowed classification of the database obtained in each evaluation as class II [23], since the field study accurately met many of the technical indications given in the international standards.

2.6. Survey questionnaire application: collection of thermal sensation responses in field study

The study was conducted in classroom buildings (spaces where students spend most of their time) which show a typical architectural typology: Reinforced concrete and block buildings where internal spaces are naturally ventilated. The general procedure for conducting observations from questionnaire applications was as follows:

a) Groups were randomly selected from the following characteristics:
- Students must attend the third semester or later (minimum stay of one year in Ensenada).
- 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 account for the most critical cold and warm moments of a typical day **[24]**.

b) Two groups of students were evaluated on a daily basis: morning/afternoon time shifts. The application started after 30 minutes from the class beginning in order to allow the acclimatization of the people to the environmental conditions of the indoor space **[5]**, **[17]**.

c) At the beginning of each evaluation, the data logging instruments were installed within the classroom as suggested by international standards in terms of position and heights **[5]** (**Figure 4**, **Figure 5**) and a questionnaire was given to each person.

d) During the evaluation, a coordinator read the questionnaire, resolved doubts, recorded environmental variables as mentioned above and carried out the questionnaire (**Figure 5**). The total evaluation time was approximately 18 min.

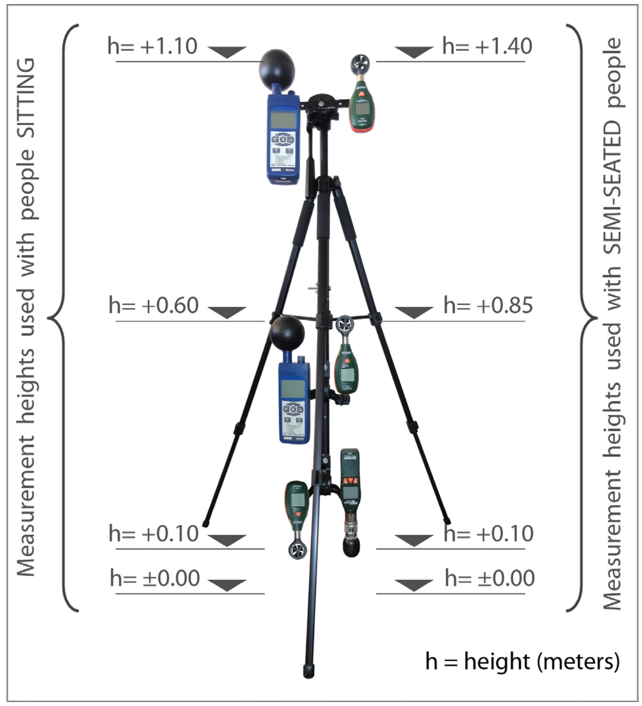


Figure 3: Measurement heights used in the field study with people sitting and semi-seated people.

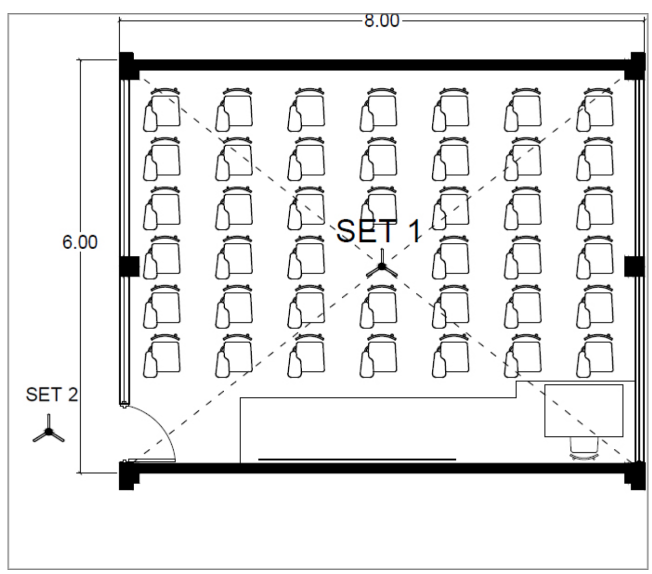


Figure 4: Distribution of measurement instruments in classrooms.

e) At the end of the questionnaire, weight and size of the subjects were optionally measured (**Figure 6**); the data were written on the report.

f) Finally, the questionnaires were collected neatly in order to define a survey serial number parameter.

Based on this methodological procedure, 45 groups and 983 observations were obtained.

Figure 5: Collection of thermal sensation responses in field study

Figure 6: Measurement of height and weight in field study.

2.7. Data processing

Data correlation analysis was carried out by Averages Intervals of Thermal Sensation method (MIST, acronym in Spanish) developed by Gómez-Azpeitia *et al.* **[25]**, which uses descriptive statistics (standard deviation, SD) in the estimation of a neutral temperature value (defined as the comfort temperature) and two ranges of thermal comfort (an extended range by applying ± 2 SD and a reduced range by applying ± 1 SD) which can be not equidistant to the neutrality value.

The standard deviation is used as a measure of the dispersion of responses and it serves to determine the strata in which they can be ordered. According to some researchers **[26]**, it is estimated that for normally distributed data, the range of ± 1 SD includes 68.3 % of the answers given by the study subjects, the range of ± 2 SD includes 95.5 % of them, and, the ± 3 SD range includes 99.7 %.

For this study, data correlation was performed according to the three levels of activity (passive, moderate and intense), without distinction by gender, age or body size.

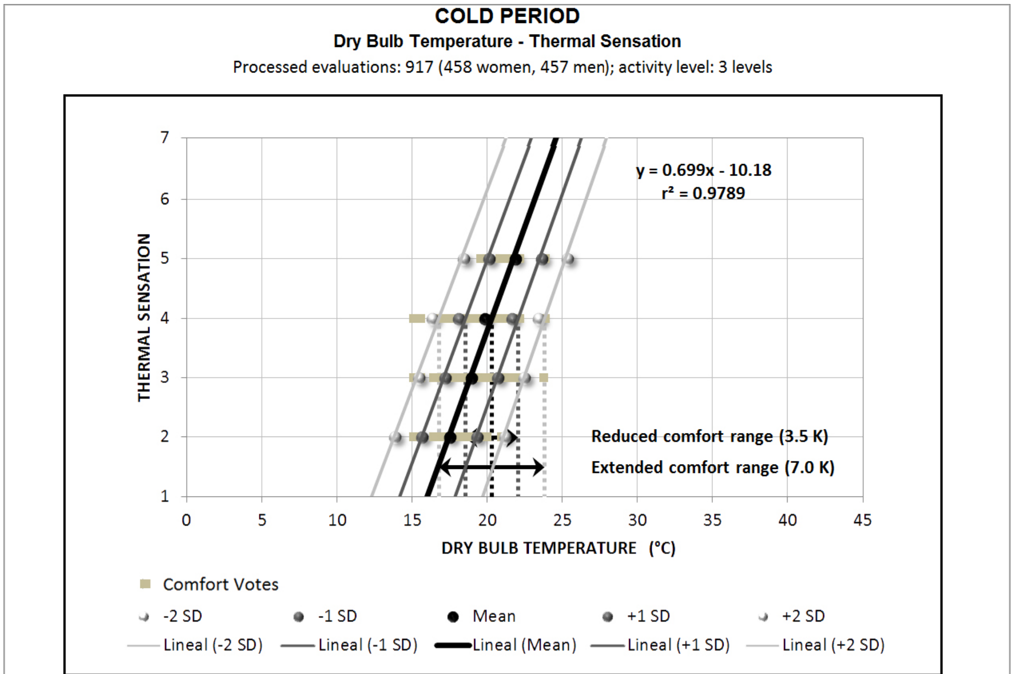
3. Results and Discussion

The degree of influence of each of the recorded environmental variables had on the subjects' thermal sensation (TS) in the field study, according to their coefficient of determination (r squared), was as follows: 1) TG (r^2 = 0.2128); 2) DBT (r^2 = 0.1977); 3) RH (r^2 = 0.0353); 4) WS (r^2 = 0.0010). Although DBT, TG, RH and WS were recorded simultaneously during the field survey application and including the emission of comfort votes, this paper only shows the results obtained from TS and DBT correlations, based on ISO 10551 and ANSI/ASHRAE 55 for cold period analysis.

Figure 7 shows the dispersion diagram generated with the correlational analysis of the TS's comfort votes and the magnitude of DBT registered each case.

Thermal comfort votes given by people are located in four of the seven TS levels contained in the subjective scale of thermal sensation proposed by international standards **[5]**, **[14]**, **[15]**: cool, slightly cool, neutral and slightly warm (TS levels 2, 3, 4 and 5, respectively) (**Figure 7**). However, 86 % of responses given by people were concentrated in TS levels slightly cool (346 votes) and neutral (442 votes) (**Table 2**). No person evaluated during the study manifested thermal sensation for any of the extreme TS levels: cold, warm or hot (TS levels 1, 6 and 7, respectively) (**Figure 7** and **Table 2**).

According to some researchers **[27]**, when the thermal sensation of people is located in any of these three TS levels, it can be considered thermal comfort since the requirements of cooling or heating are low and can easily be achieved with human physiological adaptation (acclimatization). In this sense, the above may imply that the thermal conditions during the cold period (study period) in Ensenada are accepted by 91 % of people: 38 % feel slightly cool (low heating requirements), 48 % present total acceptance (neutral) and 5 % are slightly warm (low cooling requirements). Only 9 % of people feel cool thermal conditions (79 votes) (**Table 2**).



Equation	*y = 0.67x -7.25*	*y = 0.68x -8.69*	*y = 0.70x -10.18*	*y = 0.71x -11.73*	*y = 0.73x -13.35*
r^2	*0.9785*	*0.9788*	*0.9789*	*0.9788*	*0.9784*
Neutral	**16.8**	**18.5**	**20.3**	**22.0**	**23.8**
Limits	*-3.5*	*-1.8*		*1.8*	*3.5*

Figure 7: Cold period Dry Bulb Temperature – Thermal Sensation correlation by MIST method.

According to **Figure 7**, Tn estimated from the thermal sensation is 20.3 °C (r^2 = 0.9789), with a reduced thermal comfort range from 18.5 °C to 22.0 °C (3.5 K) and an extended one from 16.8 °C to 23.8 °C (7.0 K). The comfort ranges are equidistant to Tn, the lower limits represent the same distance as the upper limits, which is interpreted as a symmetrical climate.

The mathematical equation obtained with the linear regression of each of the values (Tn and comfort ranges limits) shows that the linear regression slope has a value equal to 0.7 for Tn, a value greater than 0.7 for the upper limits of the thermal comfort ranges and a value lower than 0.7 for the lower limits of the thermal comfort ranges. However, the five estimated values have an average slope of 0.7, close to unity (**Figure 7**).

The application of questionnaires in the field study allowed to observe that the actions that people perform, such as physical and psychological adaptation type, to achieve the thermal conditions that favored their environmental perception, were: the closing of doors and windows during the day's cold moments, the simultaneous drinking of hot liquids during their activities, the increase of clothing in the morning time shift, the reduction in changes in body posture, the eventual search for places exposed to solar radiation, etc. This demonstrates that the indoors spaces in which the subjects were evaluated did not have the thermal conditions of comfort, so that an important number of subjects evaluated showed a constant search for thermal comfort in their immediate environment based on the possibilities they had at their disposal.

Based on the Auliciems and Szokolay equation **[28]** (eq. 1), the Tn is 22.0 °C, 1.7 K above the Tn value obtained in this study, which shows the degree of the psychological, physiological and attitudinal adaptation by the subjects to the local climatic conditions in the city of Ensenada. This may lead to precision of the results obtained in this type of study, since besides considering the environmental variables of architectural space, the individual perception of the people evaluated is considered.

$$Tn = 17.6 + 0.31\ Tmed \qquad (1)$$

Tn: Neutral temperature.
Tmed: Monthly mean temperature.

Statistically, the reduced comfort range includes 68.3 % of the analyzed population (± 1 SD), while the extended comfort range, 95.5 % of that population (± 2 SD) [26], which is why **Table 3** and **Figure 8** show the statistical estimate obtained for the thermal amplitude of each TS level of the extended comfort range only.

Table 3 shows the reduced and extended thermal comfort ranges obtained as a reference of thermal adaptability and thermal tolerance indoors, as well as patterns of local architectural design in Ensenada. In this matrix, the magnitude of thermal ranges can be seen in detail, and from this, according to the statistical processing performed,

Table 2: Thermal sensation levels perceived by the people during the field study.

SD	Thermal Sensation	Scale	-2 SD	-1 SD	Mean	+1 SD	+2 SD	Votes
	Hot	7						
	Warm	6						
1.7	Slightly warm	5	18.4	20.2	21.9	23.6	25.4	50
1.8	**Neutral**	**4**	**16.4**	**18.1**	**19.9**	**21.7**	**23.4**	**442**
1.8	Slightly cool	3	15.5	17.2	19.0	20.7	22.5	346
1.8	Cool	2	13.9	15.7	17.5	19.4	21.2	79
	Cold	1						

Table 3: Thermal comfort ranges (reduced and extended) estimated for cold period of Ensenada city.

Thermal sensation	Scale	Reduced range (°C)	Extended range (°C)
Hot	7	24.8 - 26.2	26.5 - 27.9
Warm	6	23.4 - 24.8	25.2 - 26.5
Slightly warm	5	22.0 - 23.4	23.8 - 25.2
Neutral	**4**	**18.5 - 22.0**	**16.8 - 23.8**
Slightly cool	3	17.1 - 18.5	15.3 - 16.8
Cool	2	15.6 - 17.1	13.8 - 15.3
Cold	1	14.1 - 15.6	12.3 - 13.8

anyone can perceive each of the subjective levels of thermal sensation.

Figure 8 shows a graph of the results contained in the previous table. The Tn and its thermal comfort ranges can be identified, as well as thermal amplitudes from which the evaluated people would feel each thermal level considered in the subjective scale. Blue bars refer to the three cold thermal sensations (*cold, cool and slightly cool*), the purple bar is of thermal comfort (*neutral*) and the red bars are the three warm thermal sensations (*slightly warm, warm and hot*). Color intensity indicates the approximation of the TS levels to the extremes thermal sensations: *cold* and *hot*.

In this sense, from a temperature below 16.8 °C people begin to perceive cold, which is intensified for every 1.7 K that reduces the temperature; likewise, from 23.8 °C people begin to perceive warmth, which is intensified every 1.6 K that increases the ambient temperature

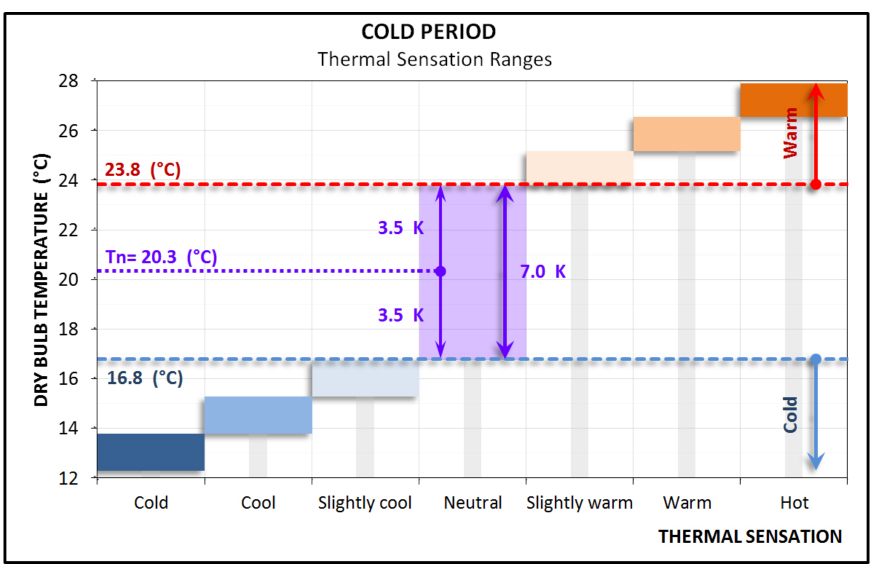


Figure 8: Thermal ranges by thermal sensation level for the cold period of Ensenada city.

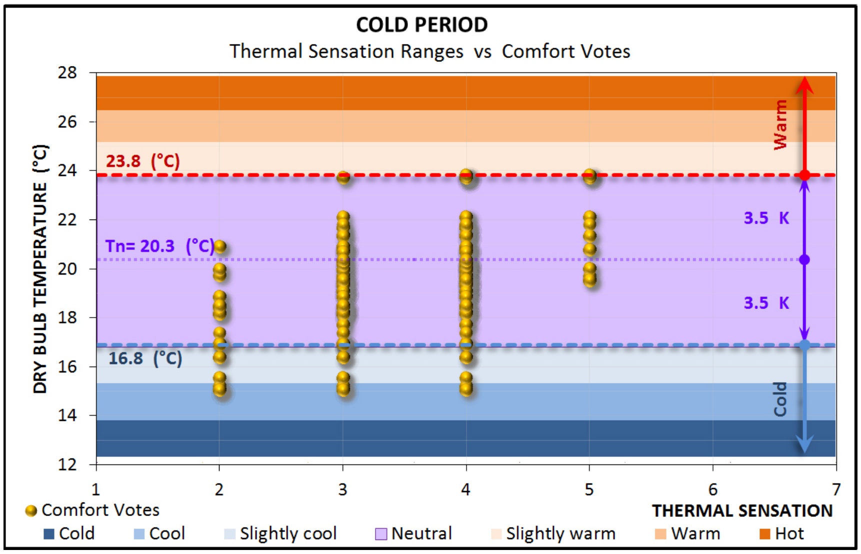


Figure 9: Thermal amplitude by TS level vs Comfort votes given by the people in the field study.

Table 4: Thermal comfort ranges (reduced and extended) estimated for cold period of Ensenada city.

Thermal sensation	Scale	Extended range (°C)	Votes	%
Hot	7	26.5 - 27.9		
Warm	6	25.2 - 26.5		
Slightly warm	5	23.8 - 25.2	29	3%
Neutral	**4**	**16.8 - 23.8**	**808**	**88%**
Slightly cool	3	15.3 - 16.8	41	4%
Cool	2	13.8 - 15.3	39	4%
Cold	1	12.3 - 13.8		

(**Figure 8**). This gives a local model of thermal comfort corresponding to the cold period in Ensenada, and from which can be derived different patterns of human performance, construction systems, architectural design, building materials, etc.

According to Figure 9 and Table 4, the thermal amplitude statistically estimated for the cold TS levels is: a) Cold, from 12.3 ° C to 13.8 ° C, b) Cool, from 13.8 ° C to 15.3 ° C and c) Slightly cool, from 15.3 ° C to 16.8 ° C; with a constant amplitude of 1.7 K. On the other hand, the thermal amplitude estimated for the warm TS levels is: a) Slightly warm, from 23.8 ° C to 25.2 ° C, b) Warm, from 25.2 ° C to 26.5 ° C and c) Hot, from 26.5 ° C to 27.9 ° C; with a constant amplitude of 1.6 K.

In Figure 9, the thermal amplitude estimated for each TS level and thermal comfort votes collected during the field study were superimposed, in order to identify, from the thermal amplitudes estimated with the MIST correlation, the percentage of people who were statistically in conditions of thermal comfort during their evaluation. Thus, it is possible to determine that 88 % of the population sample was evaluated in acceptable thermal conditions, demonstrating a high degree of adaptation by the people to achieve thermal comfort in their immediate thermal environment.

However, it is also possible to observe that 3 % of people showed slightly warm, 4 % of people perceived slightly cool and 4 % of people felt cool (Table 4). This shows that 12 % of the population sample was evaluated in thermal conditions outside the thermal range statistically accepted by people. This means that with the extended range, statistically the response of 95.5 % of the study subjects is included (Figure 7), but that during the evaluation, the indoor spaces in which 88 % of the sample was evaluated was found in thermal comfort conditions (Figure 9, Table 4).

Some limitations with which the study was conducted are:

a) The results presented here correspond only to the cold period in Ensenada; however, they are part of an extensive study that considers the four thermal periods of the year and other environmental, psychological and physiological variables simultaneously. The results of the remaining research will be published in other articles.

b) A university community was studied as a target population due to ease of access.

c) The target population corresponded to the group of students of the Autonomous University of Baja California; however, the people evaluated in the morning shift were different from those evaluated in the afternoon shift. Every day the groups to be evaluated were selected randomly, this ensured that during the study period the participants did not repeat the evaluation.

d) The thermal measurement instrument had an error range of ± 0.4 ° C.

4. Conclusions

People have the ability to adapt to the thermal conditions in the immediate environment. This adaptability is a response to constant changes in environmental conditions. Human have achieved adaptation from the periodic modification of the immediate environment: living space and type of clothing; this modification is regularly performed consciously, however, it is sometimes performed unconsciously.

The actions performed by people to adapt their living space are varied; however, those most regularly performed include the control of opening and closing doors and windows, the operation of manual, mechanical or automated devices for conditioning the thermal environment and ventilation. The periodic modification of clothing also results from the thermal period of the moment.

From the present study, it can be concluded that food and drink intake, thermal history, birthplace, physical characteristics and expectancy are factors that also affect the thermal sensation of people and, consequently, their range of thermal comfort. The thermal comfort range estimated from the correlation between DBT-TS for indoor spaces during the cold period in Ensenada, Baja California, is 16.8 °C to 23.8 °C (7.0 K), with an optimum ambient temperature of 20.3 °C. The thermal amplitude of cold and warm TS levels was statistically estimated at 1.7 K cumulative below and above the thermal comfort range, respectively, implying that the thermal conditions of the study period were favorable for 88 % of the people evaluated during this study.

The difference found between the Tn value obtained with this study and the Tn value estimated from the Auliciems and Szokolay equation is 1.7 K, which suggests an important influence from local environmental conditions on people's thermal perception. In compliance with this, the phenotypic adaptation of the subjects in a dry temperate bioclimate is a result of prolonged exposure to low temperatures throughout the year, which produces greater tolerance amplitudes and preferences compared to temperatures below Tn; in contrast, the subject reduces its thermal adaptive ability in environments with temperatures above Tn.

Neutral temperature and thermal comfort ranges can be used to identify the adjustment people apply to their thermal sensation, depending on their psychophysiological adaptation from the climatic conditions presented in the environment. In this study, the physical variables that had the greatest effect on the thermal perception of people were TG with a coefficient of determination (r^2) of 0.2128 and DBT with an r^2 of 0.1977.

Additionally, a feature observed with this study, mentioned here for the purposes of information only since it was not the main objective of this study, was that the environmental temperature represents an external factor that influences people's moods and, consequently, their interpersonal relationships, since a significant percentage of them indicated greater acceptance of low temperatures than by high temperatures, since the latter influence their relationships and communications with other people.

Appendix

Appendix 1: Questionnaire used during the application of surveys in the field studies (original language: Spanish)

Universidad Autónoma de Baja California
Facultad de Ingeniería, Arquitectura y Diseño

Línea de Investigación: Arquitectura Bioclimática
Responsable: **Dr. Arq. Julio César Rincón Martínez**
Corresponsable: Dra. Arq. Claudia M. Calderon Aguilera
Dr. Arq. Gonzálo Bojórquez Morales
Dr. Arq. Víctor A. Fuentes Freixanet

CONFORT TÉRMICO EN ESPACIOS INTERIORES: UN ESTUDIO EN BIOCLIMA TEMPLADO SECO EN ENSENADA, B. C.

Objetivo: Identificar la sensación y la preferencia térmicas de los jóvenes adultos de la ciudad de Ensenada, con el fin de estimar algunos modelos locales de confort térmico que permitan ofrecer indicadores de diseño y contribuyan en la toma de decisiones.
**Sus respuestas son muy importantes para el desarrollo de la presente investigación, por lo que se le agradecerá la honestidad y el tiempo dedicados en ellas.*

A

A. Datos de control (definidos por el líder de la entrevista)

01. Folio ______
02. Carrera (Facultad) ______
03. Fecha (dd/mm/aa) ______
04. Hora inicial (hh:mm) ______
05. Hora final (hh:mm) ______
06. Participación no. ______ / 4

B

B. Información del participante

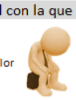
07. Nombre ______
08. Edad ______ **años**
09. Estatura ______ **m**
10. Peso ______ **kg**

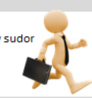
11. ¿Cuál es su sexo?
1) Hombre **2)** Mujer

12. ¿Usted padece de alguna **enfermedad crónica** *(asma, artritis, anemia, diabetes, etc.)*?
1) Si **2)** No **3)** No lo sé

13. ¿Cuál es su **estatus como habitante** de la ciudad de Ensenada? *Si su respuesta es* **2** *o* **3**, ***por favor indique su lugar de origen***
1) Originario **2)** Residente *(Lugar de origen ______)* **3)** Visitante *(Lugar de origen ______)*

14. Si usted es residente o visitante de Ensenada, ¿cuánto **tiempo** lleva habitando en la ciudad?
1) 0 - 6 meses **2)** 6 meses 1 día - 1 año **3)** 1 año 1 día - 3 años **4)** Más de 3 años

15. La **intensidad** con la que desarrolla sus actividades diarias la clasificaría como:
1) Pasiva
Relajada, **ligera** sensación de calor

2) Moderada
Normal, sensación **simultánea** de calor y sudor

3) Intensa
Activa, presencia **abundante** de calor y sudor


16. ¿Con qué **intensidad** realizó la actividad inmediata anterior a la entrevista?
1) Pasiva
Relajada, **ligera** sensación de calor
2) Moderada
Normal, sensación **simultánea** de calor y sudor
3) Intensa
Activa, presencia **abundante** de calor y sudor

17. **Tiempo** que llevaba realizando la actividad inmediata anterior:
1) 00 min - 15 min **2)** 16 min - 30 min **3)** 31 min - 45 min **4)** 46 min - 60 min o más

18. ¿Qué tipo de **vestimenta** porta en este momento?
1) Muy ligera
Shorts, playera de tirantes

2) Ligera
Pantalones ligeros, playera manga corta

3) Normal
Pantalones, playera y sudadera (normales)

4) Abrigada
Ropa gruesa

5) Muy abrigada
Ropa gruesa, gorra, bufanda, guantes

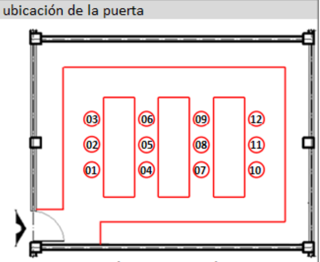

C

C. Información del espacio (respuesta auxiliada por el líder de la entrevista)

19. Con apoyo de los siguientes croquis, indique el **número de su asiento** tomando como referencia la ubicación de la puerta


Aula con butacas de paleta


Aula con mesa-bancos


Laboratorio con bancos

D

D. Sensación del ambiente interior del espacio
* Es muy importante que sus respuestas deriven de la ***SENSACION*** que percibe del ambiente interior en este momento

20. ¿Cómo clasificaría el clima en este espacio con relación a la temperatura? (sensación térmica)

1) Mucho frío	**2)** Frío	**3)** Algo de frío	**4)** Ni calor, ni frío	**5)** Algo de calor	**6)** Calor	**7)** Mucho calor
Dolor en las extremidades, requiere vestimenta gruesa	Requiere de abrigo y/o bebidas calientes	Incomodidad ocasional resuelta por la exposición directa al Sol	Sensación térmica desapercibida, desarrollo eficiente de actividades	Presencia de sed, no impide las actividades	Suda regularmente, requiere bebidas frías	Nada puede refrescarle, suda abundantemente

21. ¿Cómo considera el grado de **humedad** en el ambiente de este espacio? *(sensación de humedad)*

1) Muy húmedo	**2)** Húmedo	**3)** Algo húmedo	**4)** Normal	**5)** Algo seco	**6)** Seco	**7)** Muy seco
Incomodidad permanente, la humedad es constante y moja la	Húmedad leve en la piel, refrescante con el circular del viento	Ligera incomodidad por la humedad pero la piel continúa seca	Sensación desapercibida de humedad	Casi imperceptible, resequedad eventual en los labios	Incomodidad ocasional, resequedad en piel y labios	Incomodidad permanente; el aire, la nariz y la garganta son secos

Front view

D

22. ¿Cómo siente el **viento** en este momento? *(índices de velocidad de viento)*

1) Mucho viento — Viento fuerte, impide las actividades sedentarias
2) Viento algo fuerte — Viento intenso, causa cierta incomodidad y mueve objetos ligeros
3) Viento agradable — Leve sensación del viento sobre la piel, no causa incomodidad
4) Poco viento — No hay movimiento aparente del aire, se percibe ligero sofocamiento
5) Sin viento — Aire pesado, no se mueve, se percibe mucho sofocamiento

23. ¿Qué le parece la **luz** natural y/o artificial con la que se encuentra iluminado este espacio? *(sensación lumínica)*

1) Pésima — Incomodidad extrema, no se pueden realizar las actividades con
2) Mala — Incomodidad permanente, requiere de ajustes para lograr niveles adecuados de iluminación
3) Regular — Ligera incomodidad pero se pueden realizar las actividades sin cambio alguno
4) Buena — Sensación agradable respecto a los niveles de iluminación, no se
5) Excelente — La iluminación es perfecta, no se tiene problema de visión ni cansancio

24. El nivel de **ruido** proveniente del entorno inmediato le parece: *(sensación auditiva)*

1) Muy fuerte — Aeropuerto, ferrocarril,
2) Ruido fuerte — Vía terrestre muy transitada, concierto, etc.
3) Ruido medio — Personas conviviendo, tránsito moderado de vehículos, etc.
4) Ruido débil — Plática moderada, música apenas
5) Sin ruido — Todo en absoluto silencio

25. ¿Cómo percibe el **olor** que en este momento se presenta en el espacio? *(sensación olfativa)*

1) Muy desagradable — Olores insoportables e intensos, no se puede permanecer en el espacio
2) Desagradable — Cierto disgusto de los olores pero se pueden realizar las actividades
3) Regular — Sensación desapercibida de algún olor
4) Agradable — Cierta aceptación de los olores, contribuyen al desarrollo de las
5) Muy agradable — Aceptación total de los olores, influye positivamente en la percepción del

26. ¿Qué tan **tolerable** le parece el ambiente en este momento? *(tolerancia personal)*

1) Perfectamente tolerable — Excelente, totalmente agradable y adecuado al desarrollo de las actividades diarias
2) Tolerable — Las condiciones no son totalmente del agrado, pero son suficientes para las
3) Ni tolerable, ni intolerable — Indiferente, no despierta sensación alguna, se pueden desarrollar las actividades
4) Intolerable — Requiere de ajustes para lograr las condiciones mínimas para la actividad
5) Extremadamente intolerable — Imposible habitarlo, las condiciones generan desagrado permanente

27. ¿Cómo **consideraría** el ambiente en este lugar por lo general? *(aceptación personal del ambiente)*

1) Generalmente aceptable
2) Generalmente inaceptable

E

E. Preferencias del ambiente interior del espacio

* Es muy importante que sus respuestas deriven de cómo ***DESEARÍA*** o ***PREFERIRÍA*** las condiciones del ambiente en este momento

28. ¿Cómo preferiría estar o sentirse en este momento respecto a la **temperatura** que se presenta en el espacio? *(preferencia térmica)*

1) Mucho más fresco **2)** Más fresco **3)** Un poco más fresco **4)** Sin cambio **5)** Con un poco más de calor **6)** Con más calor **7)** Con mucho más calor

29. Si usted pudiera elegir el nivel de **humedad** que se presenta al interior del espacio, decidiría que éste fuera: *(preferencia hígrica)*

1) Mucho más húmedo **2)** Más húmedo **3)** Un poco más húmedo **4)** Sin cambio **5)** Un poco más seco **6)** Más seco **7)** Mucho más seco

30. Con base en la cantidad de **viento** que ingresa al espacio, usted preferiría: *(preferencia eólica)*

1) Más viento **2)** Sin cambio **3)** Menos viento

31. ¿Cómo preferiría que se modificara la **iluminación** del espacio en este momento? *(preferencia lumínica)*

1) Más luz **2)** Sin cambio **3)** Menos luz

32. Si pudiera modificar las **condiciones sonoras** que afectan al espacio, usted preferiría que éstas generaran: *(preferencia auditiva)*

1) Más ruido **2)** Sin cambio **3)** Menos ruido

33. ¿Cómo le gustaría que se presentara el **olor** que percibe en este momento en el espacio? *(preferencia olfativa)*

1) Más intenso **2)** Sin cambio **3)** Menos intenso

F

F. Información complementaria

34. ¿Cúal es su **estado de ánimo** con relación a las **condiciones ambientales** que presenta el espacio en este momento? *(Evaluación afectiva)*

1) Muy malo — Enfadado, inquieto, deprimido
2) Malo — Estresado, impaciente
3) Algo malo — Aburrido, somnoliento
4) Normal — Ni bueno, ni malo: Indiferente
5) Algo bueno — Relajado, concentrado
6) Bueno — Alegre, sorprendido
7) Muy bueno — Emocionado, curioso

35. ¿En qué **periodo térmico** del año usted presenta **mayor desempeño escolar**? Puede elegir más de una opción *(Desempeño escolar)*

1) Periodo frío — Invierno
2) Periodo transición Frío-Cálido — Primavera
3) Periodo cálido — Verano
4) Periodo transición Cálido-Frío — Otoño

36. ¿En qué **periodo térmico** del año usted presenta **mayor desempeño laboral** (o **doméstico**, si no trabaja)? *(Desempeño general/habitual)*

1) Periodo frío — Invierno
2) Periodo transición Frío-Cálido — Primavera
3) Periodo cálido — Verano
4) Periodo transición Cálido-Frío — Otoño

37. Notas adicionales:

Situaciones relevantes o atípicas que influyen en la percepción ambiental del participante **no consideradas en el cuestionario**: enfermedad leve, momento de depresión, periodo fisiológico mensual, exposición a cierta presión, preocupación o cualquier estado anímico distinto al ordinario, etc.

____
____
____

Back view

References

[1] V. Olgyay, "*Arquitectura y Clima. Manual de diseño bioclimático para arquitectos y urbanistas*," Barcelona: Gustavo Gili, 1963.

[2] M. Nikolopoulou and K. Steemers, "Thermal comfort and psychological adaptation as a guide for designing urban spaces," *Energy and Buildings*, vol. 35, no. 1, pp. 95-101, Jan. 2003. Doi: https://doi.org/10.1016/s0378-7788(02)00084-1

[3] J. Leech, R. Burnett, W. Nelson, S. Aaron, and M. Raizenne, M. "Outdoor air pollution epidemiologic studies", Am. J. Resp. Crit. Care, vol. 161, no. 3, 2000.

[4] S. Szokolay, "*Introduction to architectural science: The basis of sustainable design*," Elsevier, London, Architectural Press, 2004.

[5] American Society of Heating Refrigerating and Air Conditioning Engineers, "Thermal environmental conditions for human occupancy," ANSI/ASHRAE Standard 55, Atlanta, 2010.

[6] J. F. Nicol and M. A. Humphreys, "Adaptive thermal comfort and sustainable thermal standards for buildings", *Energy and Buildings*, vol. 34, no. 6, pp. 563-572, 2002. Doi: https://doi.org/10.1016/s0378-7788(02)00006-3

[7] J. Ambriz. (2016, Oct 07). *La temperatura afecta la productividad*, Investigación y Desarrollo ID, [Online]. Available: http://www.invdes.com.mx

[8] M. Humphreys, and F. Nicol. "Understanding the adaptive approach to thermal comfort", ASHRAE Transactions, vol. 104, Atlanta, pp. 991-1004, 1998.

[9] M. Humphreys. "Outdoor temperatures and comfort indoors," *Building Research & Practice*, vol. 6, no. 2, pp. 92-105, 1978. Doi: https://doi.org/10.1080/09613217808550656

[10] G. Gómez-Azpeitia, G. Bojórquez-Morales, P. Ruiz, I. Marincic, E. González and A. Tejeda, "Extreme adaptation to extreme environments: case study of hot dry, hot sub-humid, and hot humid climates in Mexico", *Journal of Civil Engineering and Architecture*. pp. 929-942, 2014.

[11] R. Romero R., G. Bojórquez G., M. Corral and R. Gallegos, "Energy and the occupant's thermal perception of low-income dwellings in hot-dry climate: Mexicali, México," *Renewable Energy*, vol. 49, pp. 267-270, Jan. 2013. Doi: https://doi.org/10.1016/j.renene.2012.01.017

[12] Oropeza-Perez, A. Petzold-Rodriguez and C. Bonilla-Lopez, "Adaptive thermal comfort in the main Mexican climate conditions with and without passive cooling," *Energy and Buildings*,vol. 145, pp. 251-258, Jun. 2017. Doi: https://doi.org/10.1016/j.enbuild.2017.04.031

[13] N. Fergus, "The limits of thermal comfort: avoiding overheating in European buildings," Chartered Institution of Building Services Engineers, London, CIBSE TM52, 2013.

[14] International Organization for Standarization ISO:10551, "Ergonomics of thermal enviroment – Assessment of the influence of the thermal environment using subjective judgement scales," Ginebra, 1995.

[15] International Organization for Standardization ISO:7726, "Ergonomics of the thermal environment - Instruments for measuring physical quantities," Second edition, Ginebra, 1998.

[16] International Organization for Standardization ISO:8996, "Ergonomics of the thermal environment - Determination of metabolic rate," Second edition, Ginebra, 2004.

[17] International Organization for Standardization ISO:7730 "Ergonomics of the Thermal Environment - Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria," Third edition, Ginebra, 2005.

[18] INEGI, "Prontuario de Información Geográfica Municipal de los Estados Unidos Mexicanos: Ensenada, Baja California," Clave geoestadística 02001, Instituto Nacional de Estadística y Geografía, México, 2009.

[19] E. García, "Modificaciones al Sistema de Clasificación Climática de Köppen," [para adaptarlo a las condiciones de la república Mexicana], Instituto de Geografía, Universidad Nacional Autónoma de México, México, 2004.

[20] V. Fuentes and A. Figueroa, "Criterios de Adecuación Bioclimática en la Arquitectura," Instituto Mexicano del Seguro Social, México, 1990.

[21] SMN-CONAGUA. Datos climáticos registrados por la Estación Meteorológica Automática BC 02 - Ensenada, B.C., período 2000-2017, datos promediados, coord. geog. 31° 53' 29" latitud N, 166° 36' 11" longitud W, 32 msnm, Servicio Meteorológico Nacional – Comisión Nacional del Agua, México, 2017.

[22] COPLADE. (2017, Jul 05) *Población de Baja California y sus Municipios*, año 5, vol. I, Baja California [Online]. Available: http://www.copladebc.gob.mx/seis/pdf/apuntePoblacionBCyMunicipiosEne14.pdf

[23] G. Brager, and R. de Dear. "Thermal Adaptation in the Built Environment: A Literature Review", *Energy and Buildings*, vol 27, no. 1, pp. 83-96, Feb. 1998. Doi: https://doi.org/10.1016/s0378-7788(97)00053-4

[24] V. Fuentes, "Clima y Arquitectura," Universidad Autónoma Metropolitana (UAM), unidad Azcapotzalco, México, 2004, pp. 190.

[25] G. Gómez-Azpeitia, R. Ruiz, G. Bojórquez, and R. Romero, "Monitoreo de Condiciones de Confort Térmico," CONAFOVI 2004-01-20, Comisión Nacional del Fondo para Vivienda, Proyecto Confort Térmico y Ahorro de Energía en la Vivienda Económica en México, Regiones de Clima Cálido Seco y Húmedo, Colima, México, Reporte Técnico (Producto 3), 2007.

[26] J. Reynaga. (2014, Oct 15) *Relación entre el Promedio y la Desviación Estándar con la Curva Normal*, Facultad de Medicina, Universidad Nacional Autónoma de México, [Online]. Available: https://documents.tips/documents/la-curva-normal-578f879d75e61.html

[27] P. O. Fanger, *Thermal Comfort: analysis and applications in environmental engineering,* New York, McGraw-Hill, 1972.

[28] A. Auliciems and S. Szokolay. "Thermal Comfort", *PLEA Note 3,* Brisbane: Passive and Low Energy Architecture International in association with Department of Architecture, The University of Queensland, 1997.