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PSYCHROMETRIC CHART FOR ECATEPEC, STATE OF MEXICO, AS A TOOL FOR HOUSING SUSTAINABLE DESIGN

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Abstract

Building sustainable design is being considered as foremost in many countries. The concept of sustainable design incorporates and integrates a variety of strategies during the design, construction and operation of building projects such as protection of occupant health, use of energy, water, and other resources more efficiently and reduction of the overall impact to the environment. In Mexico exists a Housing National Programme: "Toward a Sustainable House" which includes in its objectives the incorporation of efficient technologies, passive design strategies and sustainable materials that promote energy conservation and also help to conserve natural resources and protect the environment for present and future generations, taking into account the site analysis and obviously the climatic factors.

Mexico's climate varies depending on the regions, ranging from severe cold to hot and arid to humid. The country is crossed by the Tropic of Cancer which gives to Mexico one of the most varied weather systems in the world and consequently this has significant influences on housing design strategies. So, it would be useful to have the representation of comfort zone and climate data in the form of psychrometric chart for Ecatepec, which is the city with the highest population in the country and it is located in the State of Mexico which has the largest housing demand as tool for housing sustainable design, due to it is important to consider the climatic conditions of the area in which a house is going to be built, so that the design can provide maximum comfort for occupants while minimizing energy consumption.

Keywords: sustainable design, psychrometric chart, climate.

1. INTRODUCTION

Since the time of the very first human settlements, man has searched for and found many ways to protect himself from climatic inconveniences. Climate design has long been considered of great importance and has been studied by many enquiring minds throughout history, from Vitruvius in the first century BC (Lechner, 2001: 68) to more recent concerned parties such as Givoni (1976), Watson, et al. (1983), Olgyay (1992), Gut and Ackerknecht (1993), Brown (2001) and Lechner (2001).

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According to CONAVI (2008), Mexico has a Housing National Programme: "Toward a Sustainable House" which includes in its objectives the facilitation of access to housing to families of low incomes and the advocacy of sustainable housing development. (See Figure 1). "The problem in both urban and environment are those that originate from the increase of urban growth and are the result of the deterioration of environmental conditions." (Esparza, et al. 2012: 5). Facilitation of access means simplification in the financial process to obtain housing for people that are full, part time or self-employed and receive a minimum wage salary. In most cases, such individuals can only hope to afford vernacular housing. Advocacy of sustainable development means the incorporation of efficient technologies, passive design strategies and sustainable materials in housing that promote energy conservation and that also help to conserve natural resources and protect the environment for present and future generations. This takes into account site analysis and, more obviously, climatic factors. "A higher degree of solar, wind or biomass use as sources for heating, cooling and electricity production will change the buildings' design concept and a series of new standards have to be developed." (Musatescu and Comanescu, 2009:198).

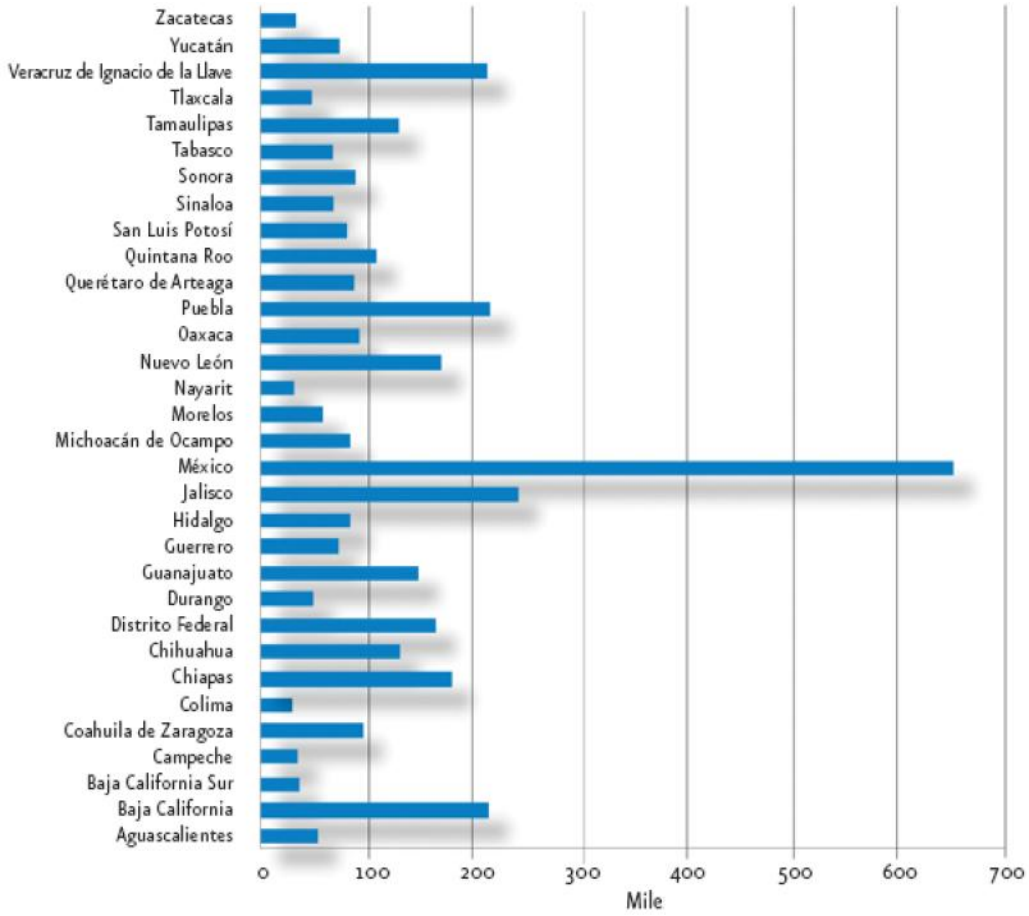

FIGURE 1 - HOUSING DEMAND IN MEXICO BY ENTITY. (SOURCE: CONAVI, 2008).

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For different purposes (statistical, educational, disaster prevention, health, etc.), several authors (INEGI 2007, CAPFCE 2007, CENAPRED 2009, CNA-SMN 2009) from the Mexican Republic have developed several climate zones maps which indicate temperature, humidity or rainfall, but they are too general to be useful.

None of them are as accurate for climate analysis as Garcia's climatic map (1973), which is an adaptation of Köppen's system taking into account particular orographic conditions of the country, or the later studies of Vidal (2005) relating to the climatic regions of Mexico. Hence, Garcia's map is appropriate for this research's selection of site that will provide the basis of the diagnostic analysis of the climate and microclimate of it, and consequently, it is also suitable for the creation of psychrometric chart for housing in Ecatepec zone.

One tool that is very useful for the selection of strategies in accordance with Lechner (2001, p.65) is the Psychrometric-Bioclimatic Chart (See Figure 2), which includes conventional heating, passive and active solar, internal gains, comfort ventilation, conventional dehumidification and air conditioning, humidification, high thermal mass, evaporative cooling, night ventilation and conventional air conditioning.

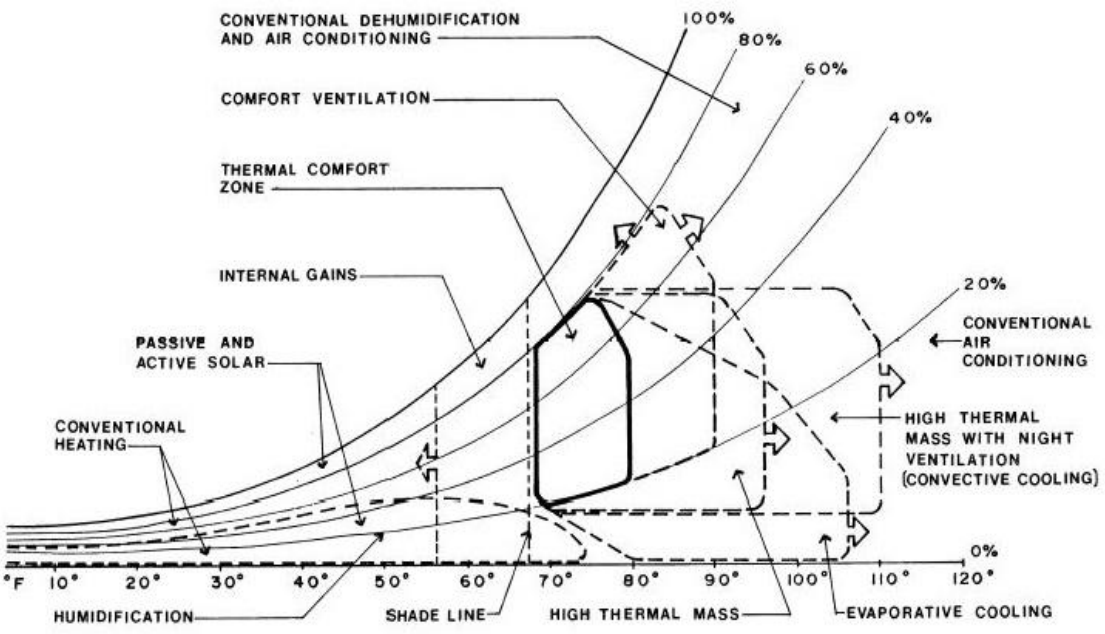

FIGURE 2 - SUMMARY OF DESIGN STRATEGIES FOR CLIMATIC DESIGN (SOURCE: LECHNER, 2001).
(From Psychrometric-Bioclimatic Chart by Givoni and Milne)

All these experts agree that the purpose of climatic design is to generate indoor thermal comfort, and in more recent years, to help with minimising energy consumption in buildings.

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2. METHODOLOGY

2.1. Overview

First of all, it is important to mention that Mexico is located in the Northern hemisphere and is divided in two by the Tropic of Cancer. Because of this fact the climate varies greatly around the country and as a consequence, this has a significant influence on housing design strategies.

In Mexico, like in other parts of the world, there exists a great interest in environmental design. However, in most cases, architects are unfamiliar with the different climates and microclimates of the country as well as with the comfort zone for each one that can be used in the design of buildings, especially in relation to housing, which represents the kind of building most in demand. "It would appear that population growth is a major factor in this looming crisis, directly affecting the built environment, therefore making urban design a crucial theme and tool in dealing with this". (Nahiduzzaman and Hass, 2008: 55). Therefore, for this reason, it is an important first step to study the appropriate climate classification to conduct to adequate design application in housing. The creation of psychrometric charts for housing has the reputation of being a useful tool and reference for designers in the application of proper design strategies in any region of the country, in this case Ecatepec, State of México.

The methodology used in this work includes; definition of central climatic region of the country, the selection of one representative city chosen using larger housing demand and larger population as criteria, and analyses topography as a microclimatic factor for the city, a selection of weather data for the representative city from the region and the representation of climate and microclimate data in a psychrometric chart for the representative city in the central region.

2.2. Selection of one representative city for the central climatic region according larger housing demand and larger population

The territory of Mexico is divided into thirty one states and one federal district; the capital city of the country. The climatic regions used in this research are based on Vidal's classification (2005), which divides the country into eleven climatic regions. Each region groups several states of the Mexican republic, or parts of them. When selecting one representative city for each region, each state was considered in relation to the level of housing demand according to CONAVI2 (2008), and then in concordance with INEGI (2009) the city in each state with the highest population was selected. Once this data was obtained, each city in each climatic region was further analysed for suitability and finally, one was chosen as a representative city for each region.

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This information is shown in Table 1 and Figure 3.

TABLE 1 - SELECTION OF ELEVEN CITIES FOR EACH CLIMATIC REGION.

STATES OF MEXICO WITH HIGH HOUSING DEMAND			
Number	*Name of the state*	*City in the state with the highest population*	*Region*
1	Estado de Mexico	Ecatepec	5
2	Jalisco	Guadalajara	5
3	Puebla	Puebla	8
4	Baja California	Tijuana	1
5	Veracruz	Veracruz	7
6	Chiapas	Comitan	10
7	Nuevo Leon	Monterrey	6
8	Distrito Federal	Iztapalapa	5
9	Guanajuanto	Leon de los Aldama	5
10	Chihuahua	Ciudad Juarez	4
11	Tamaulipas	Reynosa	6
12	Quintana Roo	Cancun	11
13	Coahuila	Saltillo	4
14	Oaxaca	Oaxaca	8
15	Sonora	Hermosillo	2
16	Queretaro	Queretaro	5
17	Michoacan	Morelia	5
18	Hidalgo	Pachuca de Soto	5
19	San Luis Potosi	San Luis Potosi	4
20	Yucatan	Merida	11
21	Guerrero	Acapulco	9
22	Sinaloa	Culiacan	3
23	Tabasco	Villa Hermosa	7
24	Morelos	Cuernavaca	8
25	Aguascalientes	Aguascalientes	5
26	Durango	Victoria de Durango	4
27	Tlaxcala	Villa Vicente Guerrero	5
28	Baja California Sur	La Paz	3
29	Campeche	Campeche	11
30	Zacatecas	Zacatecas	4
31	Nayarit	Tepic	3
32	Colima	Colima	9

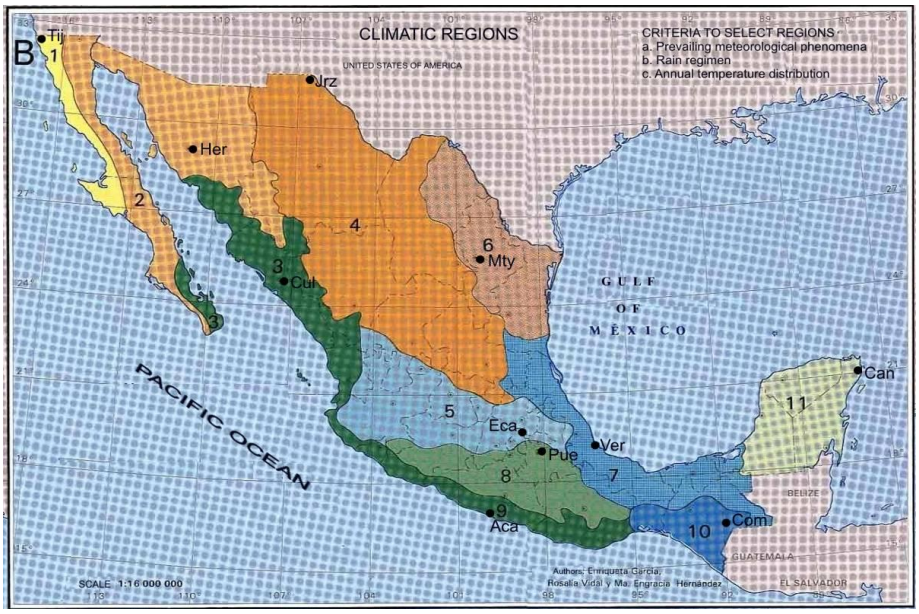

FIGURE 3 - CLIMATIC REGIONS IN MEXICO (SOURCE: VIDAL, 2005)

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As shown in Table 1 there are eleven cities in the country which correspond to the eleven climatic regions. The city of Ecatepec, in the State of Mexico is the city with the highest population and the largest housing demand in the country and corresponds to REGION 5, denominated CENTRE as it is shown in Figure 3. If it is not analysed the natural surrounding conditions of the city, it could be affected the local resources. "In the increasing concern of global warming, protection of environment is a big issue to be dealt with by the national and international communities". (Nahiduzzaman and Hass, 2008: 70).

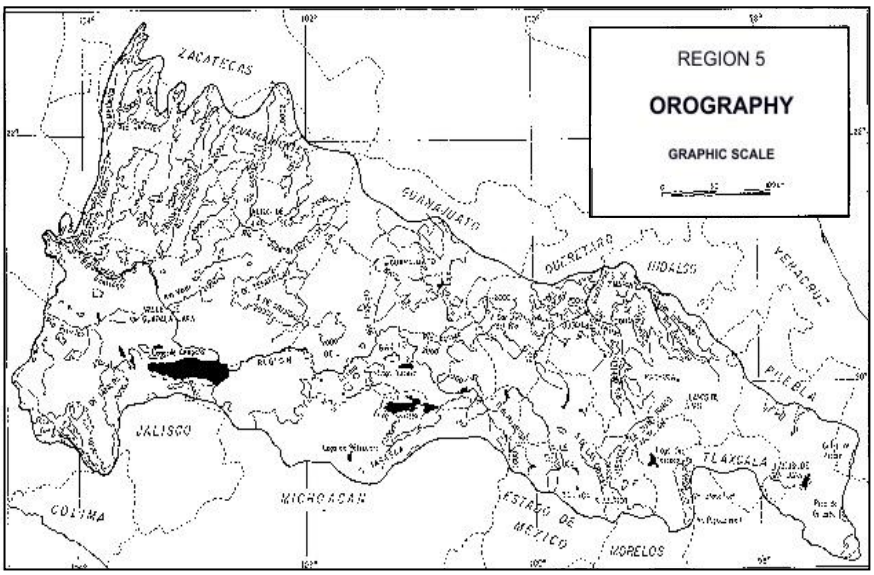
2.3. Definition of climatic region in the country and the representative city

The following information describes the main characteristics of the central climatic region in Mexico.

2.3.1. REGION 5. CENTRE

This region is situated in the south of the Mexican high plateau. Its altitude varies from 900m in the west and south-west (Rio Santiago valley, Bolaños canyon, Rio Armeria valley) to 5452m (Popocatepetl volcano). See Figure 4.

In the low valleys, located in the west of the region, the annual average temperature is over 22ºC, until an altitude of 2000m (Guadalajara, los Altos de Jalisco and Bajio valleys) when the annual temperature ranges from 18 to 22º, a prevailing warm subhumid climate. Between 2000 and 2800m altitude the climate is considered as temperate (12-18ºC) and this is the most populated zone in the country. At altitudes over 2800m, the annual average temperature is less than 12ºC and the climate is considered as cool (Nevada, de las Cruces, Ajusco, Nevado de Toluca and Malinche mountain ranges).



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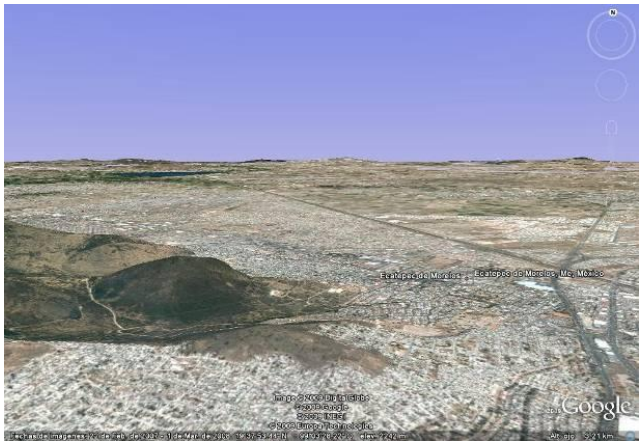
2.3.1.1. CITY: ECATEPEC, ESTADO DE MEXICO

Ecatepec is a city located in the State of Mexico, to the North East of Mexico city.

a) Topography

Source of images: Google Earth (2009)

The city of Ecatepec presents a very uneven surface. In the South East, the city is at a level between 2300 to 3050 metres above sea level



Source of images: Google Earth (2009)

Semi plain zones also exist between 2100 and 2300 metres above sea level and zones made up of plains are located to the North of the city.

b) Climatic data

The climatic data from Ecatepec city (Table 2) was obtained from the SMN (2009) and based on this data were designed graphs 1 to 4 that show mean annual temperature, mean annual relative humidity, mean annual precipitation and annual wind speed in the city respectively.

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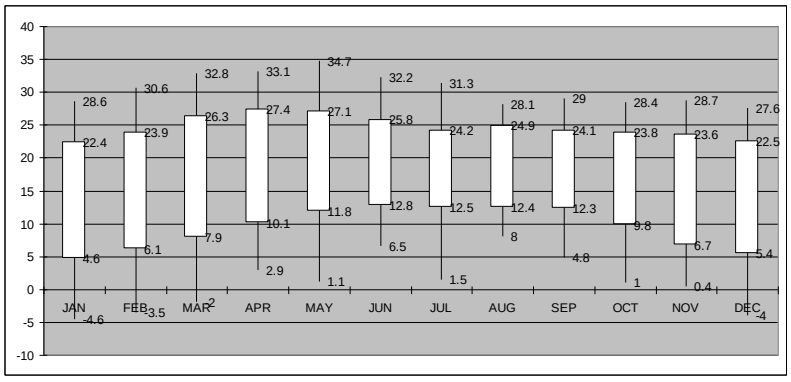
TABLE 2 - CLIMATIC DATA FROM ECATEPEC, STATE OF MEXICO

LOCATION: **ECATEPEC, ESTADO DE MEXICO**
LATITUDE N 19º 36' 03" PERIOD 1981-2000
LONGITUDE W 99º 03' 09" SOURCE: SMN-CNA
ALTITUDE 2259 masl

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
TEMPERATURE													
EXTREME MAXIMUM	28.6	30.6	32.8	33.1	34.7	32.2	31.3	28.1	29	28.4	28.7	27.6	34.7
MEAN MONTHLY MAXIMUM	22.4	23.9	26.3	27.4	27.1	25.8	24.2	24.9	24.1	23.8	23.6	22.5	24.7
MEAN	13.5	15	17.1	18.7	19.4	19.3	18.3	18.6	18.2	16.8	15.2	14	17
MEAN MONTHLY MINIMUM	4.6	6.1	7.9	10.1	11.8	12.8	12.5	12.4	12.3	9.8	6.7	5.4	9.4
EXTREME MINIMUM	-4.6	-3.5	-2	2.9	1.1	6.5	1.5	8	4.8	1	0.4	-4	-4.6
MEAN DIURNAL RANGE	17.8	17.7	18.4	17.2	15.3	13	11.7	12.5	11.9	14.1	16.9	17.1	15.3
TOTAL INSOLATION HOURS	194	158	191	201	214	180	177	185	168	185	191	209	2254
HUMIDITY													
WET BULB TEMPERATURE	8.2	8.9	9.4	10.8	12.3	13.2	13	13.4	13.3	11.8	9.7	9	11.1
MEAN RELATIVE HUMIDITY	56	53	46	50	54	61	66	64	65	61	58	59	58
MAXIMUM RH	77	73	64	69	70	77	82	80	80	80	79	80	76
MINIMUM RH	35	33	28	31	38	45	50	48	50	42	37	38	40
EVAPORATION	131	153	230	209	205	163	151	146	131	137	129	122	1908.1
PRECIPITATION													
MEAN MONTHLY	5.4	7	11.3	20.6	45.9	118.6	116.5	95.6	79.1	29.1	5.2	3.6	538
EXTREME MAXIMUM	19.9	20.3	37.9	91.3	66.4	190.1	179.1	135.6	168.3	64	18.9	15.6	190.1
MAXIMUM IN 24 HOURS	19.1	15.1	32.4	29.8	21.5	48.6	52	52.6	59.3	31.1	12.2	14	59.3
MAXIMUM IN 1 HOUR	4.7	12	4.9	18.5	11.7	23.8	32.3	21.3	42.2	18.2	8.8	10.5	42.2
PRESSURE													
MEAN VAPOUR PRESSURE	780.9	781.1	780	782	782.9	781.3	782.6	782.1	780.7	782.3	784.4	782.3	781.9
WIND													
WIND SPEED	8.8	10.1	11.1	11.3	11.1	10.8	10.6	10.8	9.9	9	8.3	8.4	10
SPECIAL PHENOMENA													
RAINFALL	1.4	2	2.8	5.2	12.9	15.3	21.8	16.9	13.8	6	2.7	1.6	102.3
CLEAR DAYS	14	12	13.3	12.5	12.1	5.9	7.6	8	7.2	10.9	12.9	13.5	129.9
PARTIALLY CLOUDY	14	12	13.3	12.5	12.1	5.9	7.6	8	7.2	10.9	12.9	13.5	129.9
CLOUDY DAYS	2.9	4.1	4.3	5	6.8	18.1	15.9	15	15.7	9.3	4.3	3.9	105.2
HAIL	0.4	0.1	0	0.1	0.4	0.1	0.4	0.7	0.4	0.1	0	0.1	2.8
FROST	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0.1
STORM	2.6	1.6	4.6	6.2	13.8	16.2	15.9	13.7	10.1	7.6	1.1	1	94.2
FOG	2.6	1.8	1	1.6	4.4	6.9	7.5	3.4	6.3	5.1	2.4	3	46

UNITS: TEMPERATURE (°C), RELATIVE HUMIDITY (%), PRECIPITATION AND EVAPORATION (mm), PRESSURE (mb), WIND SPEED (m/s) AND SPECIAL PHENOMENA (days).

Source: SMN (2009)



GRAPH 1. MEAN ANNUAL TEMPERATURE IN ECATEPEC CITY.

The mean annual temperature in the city is 17ºC, while the hottest month is May with 19.4ºC, the coldest month is January with 13.5ºC and it has a mean diurnal range of 15.3ºC.

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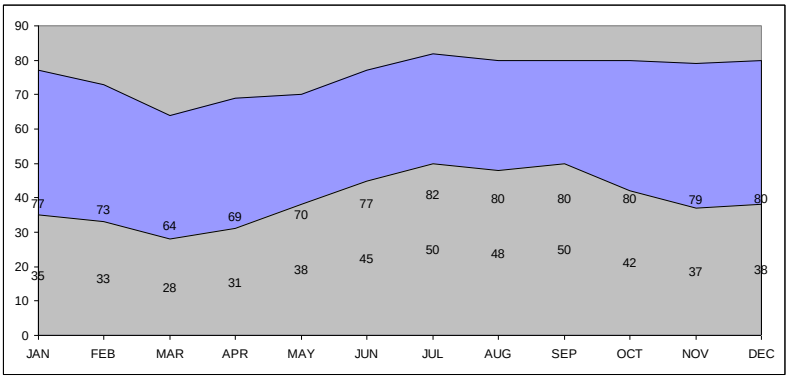
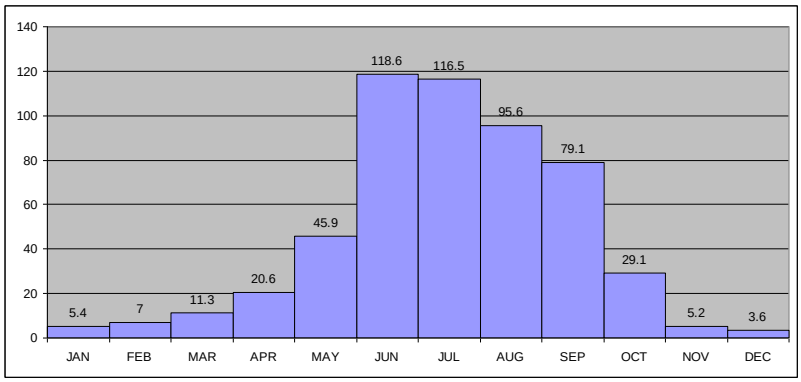


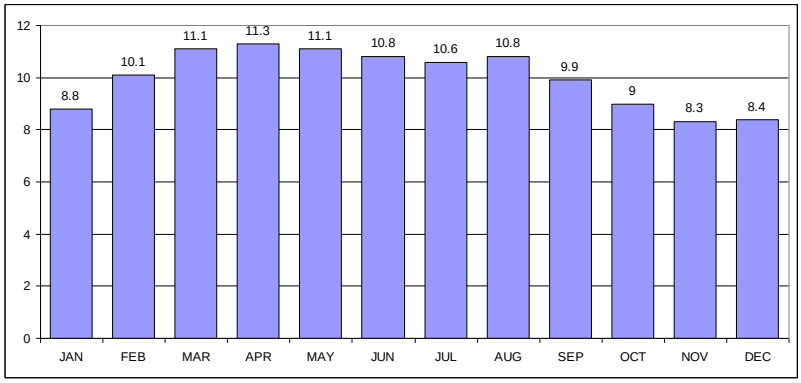
GRAPH 2. MEAN ANNUAL RELATIVE HUMIDITY IN ECATEPEC CITY.

The annual mean relative humidity is 58%. However, morning values during autumn and winter and afternoon values during winter and spring are both above and below the comfort range according to CIBSE.



GRAPH 3. MEAN ANNUAL PRECIPITATION IN ECATEPEC CITY.

The mean annual precipitation is 538 mm. June has the highest value (118.6 mm.) and December the lowest value (3.6 mm.).



GRAPH 4. ANNUAL WIND SPEED IN ECATEPEC CITY.

The annual wind speed in the city is 10 m/s and the prevailing winds come from the West and South East.

Source of climatic data: SMN [National Meteorological Service] Mexico (2009)
Graphs by: Liliana Romero Guzman

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3. PROCEDURE

The climate data of the selected city was taken from the SMN National Meteorological Service (Servicio Meteorologico Nacional in Spanish) in conjunction with the CNA National Commission of Water (Comision Nacional del Agua in Spanish).

Once having obtained the mean monthly temperature (To. av) of the warmest and coldestmonth for the city, the neutrality temperature (Tn) and the temperature of the lower (TL) and upper (TU) limits was calculated with the formulae mentioned below, in order to work out the comfort zone and plot it on the psychrometric chart.

Neutrality temperature:

$Tn = 17.6 + 0.31 \times To.\ av\ (^{o}C)$ (Szokolay, 2004, p. 20)

Temperature Lower Limit

$TL = Tn - 2.5\ (^{o}C)$ (Szokolay, 2004, p. 21)

Temperature Upper Limit

$TU = Tn + 2.5\ (^{o}C)$ (Szokolay, 2004, p. 21)

The Table 3 shows the results obtained from the calculations for the city of Ecatepec and representation of its comfort zone is also displayed on the psychrometric chart. (Figure 5).

TABLE 3 - ANALYSIS OF TEMPERATURES FOR ECATEPEC.

COMFORT ZONE			
SUMMER		**WINTER**	
WARMEST MONTH:	MAY	COLDEST MONTH:	JANUARY
MEAN TEMPERATURE:	19.4	MEAN TEMPERATURE:	13.5
THERMAL NEUTRALITY:	23.6	THERMAL NEUTRALITY:	21.8
LOWER LIMIT:	21.1	LOWER LIMIT:	19.3
UPPER LIMIT:	26.1	UPPER LIMIT:	24.3
TL	22.5	TL	20.3
TU	29.3	TU	27.0

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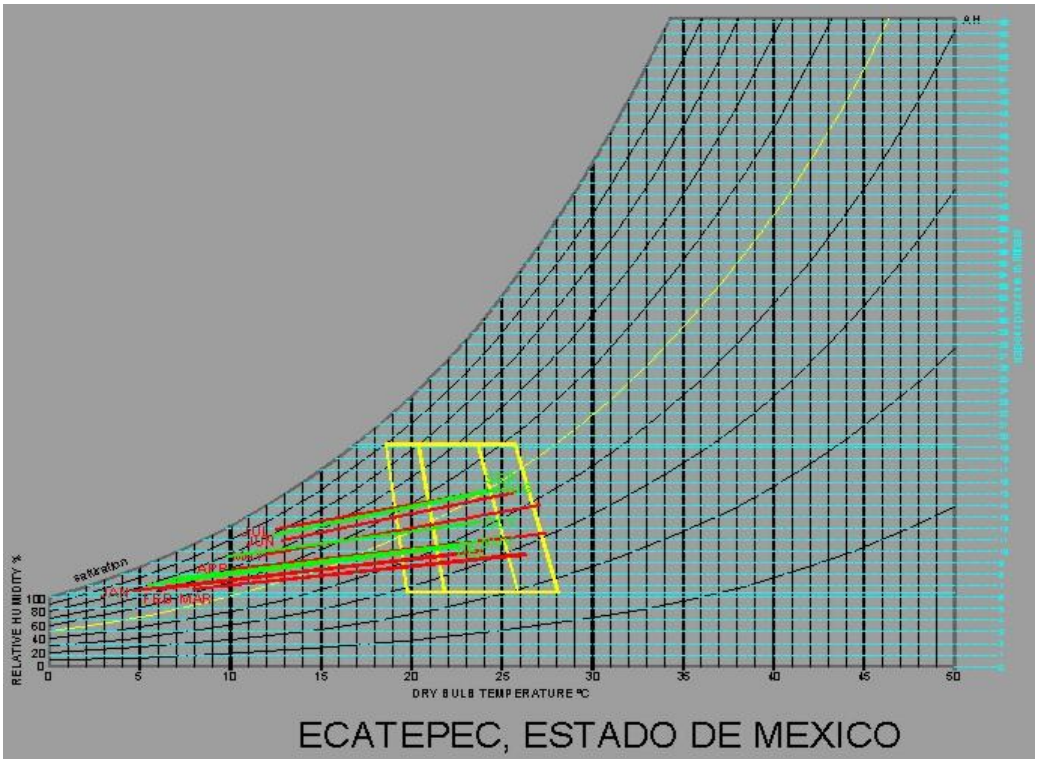

FIGURE 5 - REPRESENTATION OF COMFORT ZONE AND CLIMATE DATA IN THE FORM OF PSYCHROMETRIC CHART FOR ECATEPEC.

4. RESULTS AND DISCUSSIONS

As it is shown in the Figure 5, the comfort zone for Ecatepec is delimitated in the range of temperature from 19ºC to 26ºC during summer and from 20.5ºC to 28ºC during winter. The annual mean relative humidity is 58%. The temperatures in the morning and in the night in all the months of the year are out of comfort zone. Only temperatures of afternoon approximately from 12 h to 16 h in most of the months are inside comfort zone.

4.1 Summary

Comfort months: Only the afternoons in the whole year

Cold months: The whole year

Hot months: None

Building Requirements:

- To warm mornings and nights in the whole year.

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- Black attic and pitched roofs for collecting heat.
- Direct solar gain in order to collect solar radiation through normal windows to warm thermal mass in the room. Maximize south-facing glazing.
- Use of trombe wall, sunspace or thermal storage wall.
- Maximize reflectivity of ground and building surface outside windows facing the winter sun.
- Shape and orient the building shell to maximize exposure to sun.
- Use high-capacitance materials to store solar heat gain.
- Provide reflective panels outside of glazing to increase irradiation.
- Use skylights for solar gain and natural illumination.
- Recess structure below grade or raise existing grade for earth sheltering effect.
- Use neighboring land forms, structures or vegetation for winter wind protection.
- Shape and orient the building shell to minimize wind turbulence.

The strategies above mentioned should be considered by all the environmental designers in order to develop better built environment, so better places to live. "Effective strategies and new ways of foresight planning thinking should consider planning and regional development in a much more integrated and systemic way." (Nahiduzzaman and Hass, 2008: 71).

5. CONCLUSIONS

Nowadays, the housing design in Mexico is changing. Not only due to the modern technologies and materials to construct, but also due to the increase in the housing demand because of the high population rate. However, at the same time of these processes, the energy consumption is increasing and the negative impact in the environment is taking place.

It was very important to analyze the climatic data of the site where a construction is going to be built in order to compare and suggest the possible passive strategies for future housing design which could help in minimizing the energy consumption.

The location of Mexico in the world is privileged. The country has different climates and its topography varies too much along it, for this reason the design of housing needs to be different depending on the

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location and always shall be friendly with the nature. So, due to these facts, the significance of the psychrometric chart for Ecatepec is huge as a tool for the environmental designer.

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