Article **Journal Architecture and Design**
June 2022, Vol.6 No.15 1-12

Strategies for passive air conditioning and energy saving of a house considering the bioclimate of the place

Estrategias para la climatización pasiva y ahorro de energía de una vivienda considerando el bioclima del lugar

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DOI: 10.35429/JAD.2022.15.6.1.12 Received January 10, 2022; Accepted June 30, 2022

Abstract

The document presents different air conditioning and energy saving strategies for a building located in the Presa la Concepción subdivision of Santiago Cuautlalpan, municipality of Tepotzotlán, State of Mexico. To do this, it was necessary to consider the location of the house, the bioclimate of the place and the characteristics of the building envelope, later the temperature and hourly humidity tables of the place were determined and the thermal comfort zone was established. Afterwards, the psychrometric process involved, the thermal balance or resulting sensible heat (sensible heat gains by occupants, equipment, solar radiation and environment) and the air flow required by the equipment were determined. With the results of the thermal balance, some strategies were proposed, first considering thermal insulation and coatings, where the energy savings that could be had when implementing these strategies were included. Second, with passive air conditioning strategies considering passive systems, wind and sun.

Thermal balance, Passive air conditioning, Energy saving

Resumen

En el documento se presentan diferentes estrategias de climatización y ahorro de energía, para una edificación ubicada en el fraccionamiento Presa la Concepción de Santiago Cuautlalpan, municipio de Tepotzotlán, Estado de México. Para realizarlo fue necesario considerar la ubicación de la vivienda, el bioclima del lugar y las características de la envolvente de la edificación, posteriormente se determinaron las tablas de temperatura y humedad horaria del lugar y se estableció la zona de confort térmico. Después se determinó el proceso psicrométrico involucrado, el balance térmico o calor sensible resultante (ganancias de calor sensible por ocupantes, equipos, radiación solar y medio ambiente) y el flujo de aire requerido por el equipo. Con los resultados del balance térmico se plantearon algunas estrategias, primero considerando aislantes térmicos y recubrimientos, en donde se incluyó el ahorro de energía que se podía tener al poner en marcha esas estrategias. Segundo, con estrategias de climatización pasiva considerando sistemas pasivos, al viento y al sol.

Balance térmico, Climatización pasiva, Ahorro de energía

Citation: HERNÁNDEZ-GÓMEZ, Víctor Hugo, MORILLÓN-GÁLVEZ, David, OLVERA-GARCÍA, Omar and GUZMAN-TINAJERO, Pedro. Strategies for passive air conditioning and energy saving of a house considering the bioclimate of the place. Journal Architecture and Design. 2022. 6-15:1-12.

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Introduction

The internal temperature of the human body is around 36 °C, when it suffers an increase in heat, it expels it from the organism through drops of water called sweat, if the heat continues to increase, the organism will tend to become dehydrated. If the body suffers a loss of heat, i.e. it is in a cold environment, the body begins to contract and expand its muscles, which we call shivering, to generate heat by friction, if the body temperature continues to decrease, the body stops sending blood to the organs that are not vital to reduce heat loss, if it continues to decrease, the body ceases to have mobility until it reaches hypothermia. When the body is not able to control its internal temperature on its own, it is necessary to use clothing, spaces protected by walls and ceilings and even air-conditioning systems. But it is not only important to control the temperature and humidity of the environment for the human body, but it is also used for the preservation of food, important documents, computer equipment, etc.

Unfortunately, these air conditioning systems consume a large amount of electrical energy, contributing to the emission of greenhouse gases. Fortunately, it is possible to reduce the size of the air conditioning system to be used and even replace it with passive systems that do not require electricity and use renewable energies such as wind and sun. This article presents strategies for air conditioning a house located in Fraccionamiento Presa la Concepción, including techniques for the insulation of the envelope as well as passive systems.

Santiago Cuautlalpan, located at a latitude of 19.685°, longitude of -99.286° and altitude of 2,340 m above sea level, is near the centre of Tepotzotlán, Estado de México. Within the town is the ecotourism park La Concepción dam from which the Tepotzotlán deep river and the Zanja Real Canal are derived, which are the main source of water supply for the surrounding towns. The Hacienda la Concepción subdivision is located in the vicinity of the La Concepción dam. It is classified as a mixed housing, commercial and service urban complex.

Climatological data

According to data provided by the website weatherspark.com, which performs statistical analysis of historical hourly weather reports and model reconstructions from 1 January 1980 to 31 December 2016 of the four stations near Santiago Cuautlalpan; in Santiago Cuautlalpan the time of the year considered as temperate is from 22 March to 7 June, with April being the warmest month of the year with an average maximum temperature of 25 °C and a minimum of 10 °C. The cool season is from 7 November to 3 February, with January being the coldest month of the year with an average minimum temperature of 5 °C and a maximum of 21 °C. Table 1 shows the maximum and minimum temperature values for the area, combining historical data presented on the weatherspark.com website and climatological data from the climatological station located at Presa la Concepción.

Prom	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Max °C	21.2	23	25.2	26.5	26.1	24.5	22.8	23	22.4	21.9	21.9	21.5
Averange °C	12.1	13.3	15.2	16.9	17.5	17.5	16.5	16.7	16.4	14.9	13.4	12.3
Min °C	3	3.5	5.1	7.2	8.8	10.4	10.2	10.3	10.4	7.9	4.8	3.1

Table 1 Maximum and minimum monthly average ambient temperature values for Presa la Concepción.
Source: On-site weather station

The rainy season is concentrated in the months of April to November, with July being the month with the highest rainfall with 117 millimetres of rain on average and December the lowest with 3 millimetres of rain on average. In terms of wind, from 24 January to 26 April, average wind speeds of more than 8.2 kilometres per hour were reported, with March being the month with the highest wind speed, averaging 9.2 kilometres per hour. From 26 April to 24 January the wind speed is lower with December being the month with the lowest wind speed averaging 7.4 kilometres per hour. Table 2 shows the statistical data on cloudiness, rainfall and wind and figure 1 shows the predominant wind direction.

Fraction	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Cct	Non	Dec
Cloudy %	40	34	35	40	49	75	84	85	87	72	49	44
Clear %	60	66	65	60	51	25	16	15	13	28	51	56
Rain mm	6.9	6.4	6.2	13.1	34.6	103.7	116.8	109.6	106.6	45.4	10.0	3.1
Wind km/h	8.0	8.6	9.2	8.6	8.1	8.3	8.2	8.3	8.7	8.2	7.5	7.4

Table 2 Monthly average cloud cover, rainfall and wind for Santiago Cuautlalpan
Source: https://es.weatherspark.com/y/5666/Clima-promedio-en-Santiago-Cuautlalpan-M%C3%A9xico-durante-todo-el-a%C3%B1o

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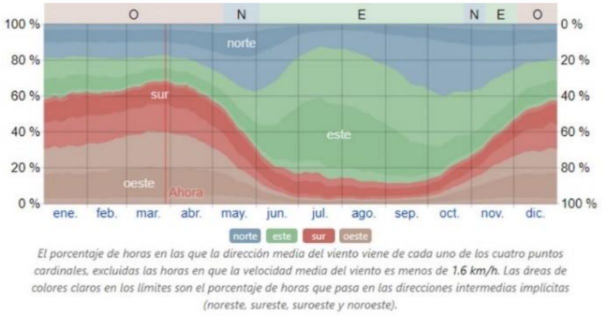

Figure 1 Wind direction in Santiago Cuautlalpan
Source: https://es.weatherspark.com/y/5666/Clima-promedio-en-Santiago-Cuautlalpan-M%C3%A9xico-durante-todo-el-a%C3%B1o

Regarding solar radiation, from March 9th to June 6th is the season with the highest solar radiation, presenting average values higher than 6.9 kWh/m^2, being April the month that receives the highest radiation with average values of 7.3 kWh/m^2. From 8 November to 25 January is the period with the lowest direct radiation, with average values of less than 5.4 kWh/m^2, and December has the lowest average value of 5.0 kWh/m^2. Table 3 shows the average values of solar radiation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar energy kWh	5.3	6.2	7.0	7.4	7.2	6.5	6.3	6.2	5.8	5.7	5.3	5.0

Table 3 Monthly average incident radiation of Santiago Cuautlalpan
Source: https://es.weatherspark.com/y/5666/Clima-promedio-en-Santiago-Cuautlalpan-M%C3%A9xico-durante-todo-el-a%C3%B1o

Comfort zone and hourly temperature and humidity table

The information from the Presa la Concepción weather station is fed into the Biosol software (Preciado, 2010) from which the thermal comfort zone shown in figure 2 and tables 4 and 5 of temperature and hourly humidity of Presa la Concepción are obtained.

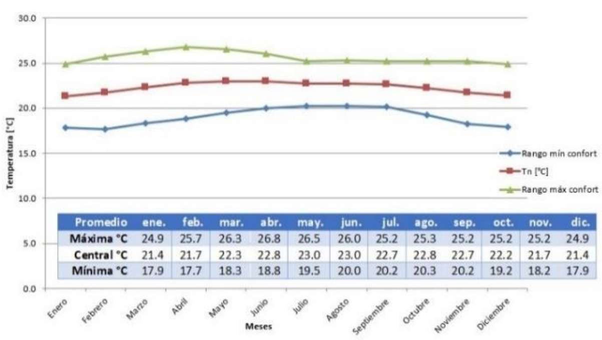

Figure 2 Comfort zone of Presa la Concepción
Source: Own elaboration with Biosol software (Preciado, 2010)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	7.8	8.4	9.9	11.5	12.5	13.3	12.9	13.1	13.2	11.4	9.2	8.0
01:00	6.9	7.5	9.0	10.7	11.8	12.8	12.3	12.6	12.7	10.7	8.4	7.1
02:00	6.2	6.7	8.3	10.0	11.2	12.3	11.9	12.1	12.2	10.2	7.7	6.3
03:00	5.5	6.1	7.6	9.5	10.7	11.9	11.6	11.8	11.9	9.7	7.2	5.7
04:00	5.0	5.6	7.1	9.0	10.3	11.6	11.3	11.5	11.6	9.4	6.7	5.2
05:00	4.6	5.1	6.7	8.6	10.0	11.4	11.1	11.2	11.3	9.1	6.3	4.8
06:00	4.3	4.8	6.4	7.2	9.0	10.7	10.4	10.4	10.4	8.8	6.0	4.4
07:00	3.2	4.1	6.3	9.2	11.4	12.8	12.2	11.9	11.3	8.5	5.1	3.3
08:00	5.7	7.2	10.0	13.2	15.2	16.0	15.1	14.6	13.7	10.8	7.5	5.6
09:00	9.7	11.7	14.8	17.8	19.2	19.3	18.0	17.6	16.5	14.1	11.4	9.7
10:00	14.0	16.1	19.1	21.7	22.5	21.8	20.3	20.1	19.0	17.2	15.3	13.9
11:00	17.4	19.6	22.4	24.5	24.7	23.5	21.9	21.8	20.9	19.6	18.5	17.5
12:00	19.8	21.8	24.4	26.0	25.8	24.4	22.6	22.8	22.0	21.2	20.6	19.9
13:00	20.9	22.8	25.1	26.4	26.0	24.4	22.7	23.0	22.4	21.8	21.7	21.2
14:00	21.1	22.8	24.9	26.0	25.4	23.9	22.3	22.6	22.2	21.7	21.8	21.4
15:00	20.5	22.0	23.9	24.9	24.3	22.9	21.4	21.8	21.5	21.1	21.2	20.8
16:00	19.3	20.7	22.4	23.3	22.9	21.7	20.4	20.8	20.6	20.1	20.1	19.7
17:00	17.8	19.0	20.7	21.6	21.3	20.5	19.2	19.7	19.5	18.9	18.7	18.2
18:00	16.2	17.2	18.8	19.8	19.7	19.2	18.1	18.5	18.4	17.6	17.1	16.5
19:00	14.5	15.5	17.0	18.1	18.2	17.9	17.0	17.3	17.3	16.4	15.5	14.8
20:00	12.9	13.7	15.2	16.5	16.8	16.7	15.9	16.3	16.3	15.1	14.0	13.2
21:00	11.4	12.2	13.6	15.0	15.5	15.7	15.0	15.3	15.4	14.0	12.6	11.7
22:00	10.0	10.7	12.2	13.7	14.3	14.8	14.2	14.5	14.5	13.0	11.3	10.3
23:00	8.8	9.5	11.0	12.5	13.3	14.0	13.5	13.7	13.8	12.1	10.2	9.0

Table 4 Hourly average monthly ambient temperature values for Presa la Concepción
Source: Own elaboration with Biosol software (Preciado, 2010)

Hour (TSV)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	70	67	64	64	68	74	76	76	76	72	69	69
01:00	72	69	66	66	69	75	78	77	78	74	71	72
02:00	74	71	68	68	71	77	79	79	80	76	73	74
03:00	76	73	69	69	72	78	80	80	81	77	75	75
04:00	78	74	71	70	73	79	81	81	82	78	76	77
05:00	79	75	72	71	74	80	82	82	83	79	77	78
06:00	80	76	72	75	77	82	84	84	86	80	78	79
07:00	83	78	73	70	71	75	78	80	83	81	80	82
08:00	76	70	64	60	61	65	69	70	75	74	73	76
09:00	64	58	52	49	50	55	59	61	65	63	63	64
10:00	52	47	42	40	41	47	51	52	56	54	52	53
11:00	43	38	34	33	36	42	46	47	50	46	43	43
12:00	36	32	29	29	33	40	43	44	46	41	37	36
13:00	33	30	28	28	32	40	43	43	45	39	34	32
14:00	32	30	28	30	34	41	45	44	46	40	33	32
15:00	34	32	31	32	37	44	48	47	48	41	35	33
16:00	37	35	34	36	40	48	51	50	51	45	38	37
17:00	42	39	38	40	44	52	55	54	54	48	42	41
18:00	46	44	43	44	49	56	59	58	58	52	47	45
19:00	51	49	47	49	53	60	62	61	62	56	51	50
20:00	55	53	51	52	56	63	66	65	66	60	55	55
21:00	60	57	55	56	60	66	69	68	69	64	59	59
22:00	64	61	58	59	63	69	72	71	72	67	63	63
23:00	67	64	61	62	65	72	74	73	74	70	66	66

Table 5 Hourly values of monthly average relative humidity of Presa la Concepción
Source: Own elaboration with Biosol software (Preciado, 2010)

Characteristics of the dwelling

The property has an almost rectangular geometry with an area of 317.836 m^2, the building has a ground floor and first level, with 262.32 m^2 and 3 parking spaces. The ground floor includes the pedestrian access, entrance hall, staircase, study, toilet, living room, dining room and kitchen. The upper floor contains 4 bedrooms, each with bathroom. The facades of the house, the longitudinal sections and the cross sections, are shown in figures 3, 4 and 5.

Figure 3 Façades of the house
Source: Own elaboration

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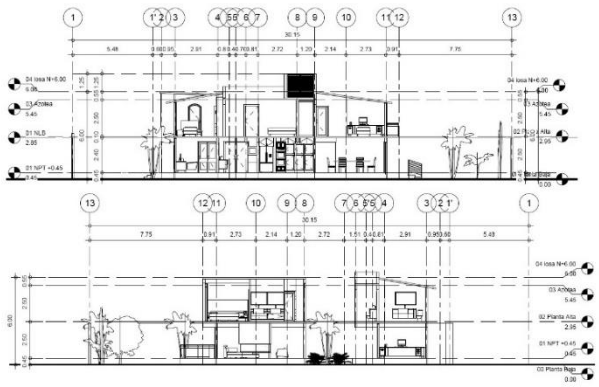

Figure 4 Longitudinal sections of the house
Source: Own elaboration

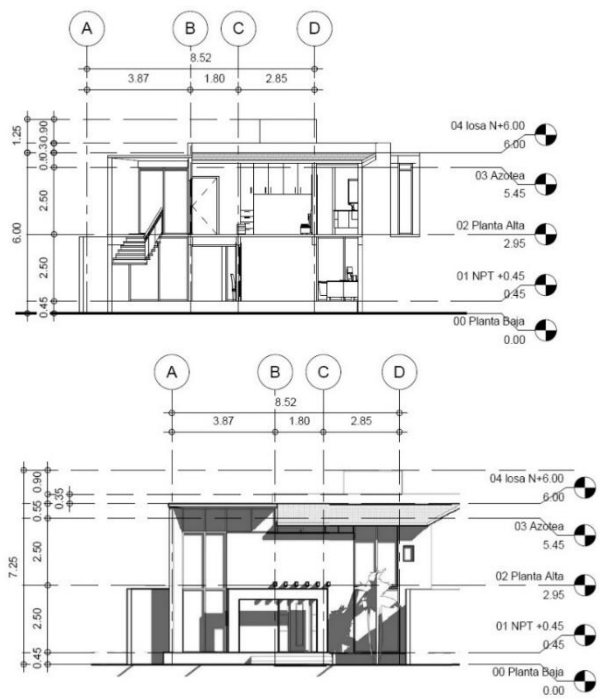

Figure 5 Cross-sections of the dwelling
Source: Own elaboration

Psychrometric properties of the air

For the analysis it is necessary to know the psychrometric properties of the ambient air, the air inside the building and the comfort temperature. According to data from the Presa la Concepción weather station and those reported on the weatherspark.com website, April is the hottest month and January the coldest, so the analysis will be carried out for these months of the year. The internal temperature and comfort temperature reported for these months are 30 °C and 22.8 °C for April and 16 °C and 21.4 °C for January. The calculated properties are presented in table 6.

		State	T_{BS} °C	ϕ %	W kgv/kga	H kJ/Kg
January	Internal	A	16.0	50	0.0056677	30.29
	Comfort	B	21.4	50	0.0078866	41.36
April	Internal	A	27.0	50	0.0112817	55.65
	Comfort	B	22.8	50	0.0086166	44.63

Table 6 Specific humidity and enthalpy for the analysis
Source: Own elaboration

Psychrometric process involved

To determine the psychrometric process, the amount of moisture and heat gained or lost in the process, the following procedure is followed:

For the month of January.

$\Delta W = W_B – W_A$

$\Delta W = (0.0078866 - 0.0056677)$ kgv/kga

$\Delta W = 0.0022188$ kgv/kga

(+) Humidification

$\Delta h = h_B – h_A$

$\Delta h = (41.36 – 30.29)$ KJ/Kg

$\Delta h = 11.07$ kJ/kg

A Heating process with humidification is required.

For the month of April.

$\Delta W = W_B – W_A$

$\Delta W = (0.0086166 - 0.0112817)$ kgv/kga

$\Delta W = - 0.002665078$ kgv/kga

(-) dehumidification

$\Delta h = h_B – h_A$

$\Delta h = (44.63 – 55.65)$ KJ/Kg

$\Delta h = - 11.02$ kJ/kg

(-) Cooling

A Cooling process with dehumidification is required.

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Determination of the sensible load of the dwelling

a) Heat input per inhabitant

The dwelling is occupied by four persons, therefore the results are presented in table 7.

	Quantity	W/H factor	Subtotal W
Inhabitants	4	139.53	558.12
		Total	**558.12**

Table 7 Heat contributed by the inhabitants
Source: Own elaboration

b) Heat input by equipment

Table 8 shows the equipment reported in the two levels of the dwelling.

Ground floor	Power W	Quantity	W/H factor	Subtotal W
40-inch TV	90	1	0.999	89.91
Blu-ray	34	1	0.999	33.966
Cooker	635	1	0.999	634.365
Refrigerator	400	1	0.999	399.6
Washing machine	800	1	0.999	799.2
Spotlights	25	12	0.999	299.7
Ground floor			**Total**	**2256.741**

First level	Power W	Quantity	W/H factor	Subtotal W
40-inch TV	90	4	0.999	359.64
Blu-ray	34	4	0.999	135.86
Spotlights	25	10	0.999	249.75
			Total	**745.25**

Table 8 Heat provided by equipment
Source: Own elaboration

c) Heat flow with respect to the environment

Based on the plans of the dwelling, the following is shown:

Ground floor

The south wall is 17 m long by 2.4 m high, of which 8.5 m^2 are window area of 6 mm thickness, K = 0.720 W/m°C and transmittance of 0.8. It has a 3.9 m^2 wooden door with a thickness of 5 cm, k = 0.140 W/m°C and an absorptance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m°C, 1 cm of internal plaster rendering with K = 0.280 W/m°C and 1 cm of external sand cement mortar rendering with K = 1.4 W/m°C.

The west wall is 14.46 m long by 2.4 m high, of which 6.6 m^2 is 6 mm thick window area, K = 0.720 W/m°C and transmittance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m°C, 1 cm of internal plaster rendering with K = 0.280 W/m°C and 1 cm of external sand cement mortar rendering with K = 1.4 W/m°C.

The north wall is 17 m long by 2.4 m high, of which 16 m^2 is window area of 6 mm thickness, K = 0.720 W/m°C and transmittance of 0.8. It has a 3.9 m^2 wooden door with a thickness of 5 cm, k = 0.140 W/m°C and an absorptance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m°C, 1 cm of internal plaster rendering with K = 0.280 W/m°C and 1 cm of external sand cement mortar rendering with K = 1.4 W/m°C.

The east wall is 14.46 m long by 2.4 m high, of which 3 m^2 is window area of 6 mm thickness, K = 0.720 W/m°C and transmittance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m°C, 1 cm of internal plaster plaster with K = 0.280 W/m°C and 1 cm of external sand-cement mortar plaster with K = 1.4 W/m°C.

The ceiling is 20 cm of medium concrete with K = 1.2 W/m°C, it has 1 cm of internal plaster with K = 0.280 W/m°C and at the top it has 1 cm thick tiles with K = 0.820 W/m°C.

Upper floor

The south wall is 17 m long by 2.4 m high, of which 9.8 m^2 is window area of 6 mm thickness, K = 0.720 W/m°C and transmittance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m°C, 1 cm of internal plaster rendering with K = 0.280 W/m°C and 1 cm of external sand cement mortar rendering with K = 1.4 W/m°C.

The west wall is 14.46 m long by 2.4 m high, of which 10.46 m^2 is window area of 6 mm thickness, K = 0.720 W/m°C and transmittance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m°C, 1 cm of internal plaster rendering with K = 0.280 W/m°C and 1 cm of external sand-cement mortar rendering with K = 1.4 W/m°C.

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The north wall is 17 m long by 2.4 m high, of which 18 m^2 are window area of 6 mm thickness, K = 0.720 W/m °C and transmittance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m °C, 1 cm of internal plaster rendering with K = 0.280 W/m °C and 1 cm of external sand cement mortar rendering with K = 1.4 W/m °C.

The east wall is 14.46 m long by 2.4 m high, of which 5.5 m^2 are window area of 6 mm thickness, K = 0.720 W/m °C and transmittance of 0.8. The wall is composed of 15 cm thick partition wall with K = 0.560 W/m °C, 1 cm of internal plaster plaster with K = 0.280 W/m °C and 1 cm of external sand-cement mortar plaster with K = 1.4 W/m °C.

The ceiling is 20 cm of medium concrete with K = 1.2 W/m °C, external absorptance of 0.8 and has 1 cm of internal gypsum plaster rendering with K = 0.280 W/m °C.

The entire room envelope will be considered to be exposed to the environment. Table 9 condenses the data for the elements that make up the envelope. The method considers performing the analysis for each element that makes up the envelope and determining its overall heat transfer coefficient. Table 10 shows the results obtained.

Ground floor	**Length (m)**	**Height (m)**	**A. total (m^2)**	**A. window (m^2)**	**A. door (m^2)**	**A. wall (m^2)**
North Wall	17.00	2.40	40.80	16.00	3.90	20.90
South Wall	17.00	2.40	40.80	8.50	3.90	28.40
East Wall	14.46	2.40	34.70	3.00	0	31.70
West Wall	14.46	2.40	34.70	6.60	0	28.10
Roof	17.00	14.46	**245.82**			
			Total	**34.10**	**7.80**	**109.11**

First level	**Length (m)**	**Height (m)**	**A. total (m^2)**	**A. window (m^2)**	**A. wall (m^2)**
North Wall	17.00	2.40	40.80	18.0	22.80
South Wall	17.00	2.40	40.80	9.80	31.00
East Wall	14.46	2.40	34.70	5.50	29.20
Muro Oeste	14.46	2.40	34.70	10.46	24.24
Techo	17.00	14.46	**245.82**		
			Total	**43.76**	**107.25**

Table 9 Dimensions of the elements that make up the envelope of the dwelling
Source: Own elaboration

Ground floor / Upper floor	**R m^2°C/W**	**U W/m^2°C**
Wall	0.60	1.66
Glass	0.30	3.33
Wood	0.65	1.54
Ceiling	0.51	1.98

Table 10 Overall heat transfer coefficient for the analysis
Source: Own elaboration

With these results, the sensible heat flow can be obtained for each element of the envelope and for each season, the results are presented in table 11.

Ground Floor	Area (m^2)	U W/m^2°C	ΔT January	ΔT April	Q January W	Q April W
Wall	109.11	1.66	-13	1	-2354.66	181.13
Glass	34.10	3.33	-13	1	-1477.67	113.67
Wood	7.80	1.54	-13	1	-156.29	12.02
				Total	**-3988.62**	**306.82**

First level	Area (m^2)	U W/m^2°C	ΔT January	ΔT April	Q January W	Q April W
Wall	107.25	1.66	-13	1	-2314.52	178.04
Glass	43.76	3.33	-13	1	-1896.27	145.87
Wood	0	1.54	-13	1	0	0
Ceiling	245.82	1.98	-13	1	-6312.51	485.58
				Total	**-10523.29**	**809.48**

Table 11 Sensible heat flux with respect to the environment
Source: Own elaboration

d) Heat contribution by solar radiation

The months of January and April will be considered for the analysis, with average solar irradiation values reported by the weatherspark.com website of 5.3 KW and 7.4 KW respectively. Figure 6 shows the solar diagrams for the locality of Presa la Concepción, municipality of Tepotzotlán, State of Mexico, which will be used for the analysis.

For the analysis, 11 o'clock in each month will be considered, therefore, for the month of January there is a solar height of 48° and azimuth of 20° SE; and for the month of April there is a solar height of 74° and azimuth of 29° ES, which means that only the south and east façades receive solar radiation. Figure 7 shows the triangles formed by the azimuth and solar height for the east, south and roof orientations.

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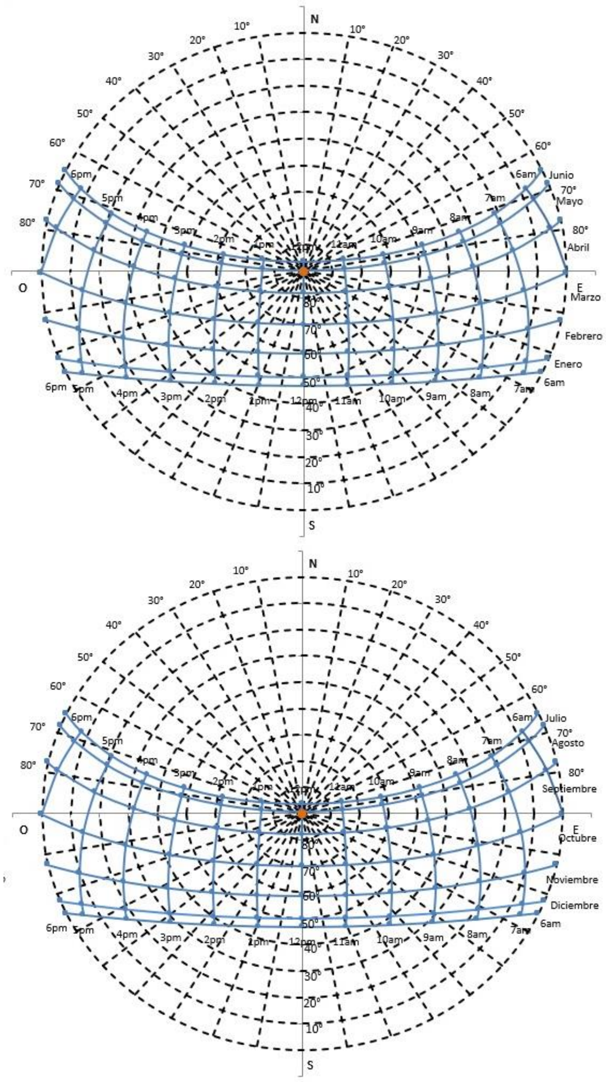

Figure 6 Solar diagrams for Presa la Concepción, latitude 19.69
Source: Own elaboration with Biosol software (Preciado, 2010)

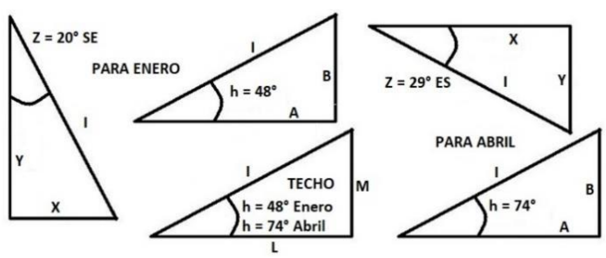

Figure 7 Triangles formed with azimuth z and solar height h for the application case
Source: Own elaboration

Analysis for the east

The leg that is perpendicular to the east wall is X, therefore:

$senz = Y/I$ therefore $Y = I\ senz$

$cosz = X/I$ therefore $X = I\ cosz$

With respect to the solar height, the cathetus that is perpendicular to the wall is A and the value of the irradiation I will be Icosz, therefore:

$senh = B/Icosz$ therefore $B = I\ cosz\ senh$

$cosh = A/Icosz$ therefore $A = I\ cosz\ cosh$

The formulas to be used for the east façade will be:

$Qre = A\ \tau\ I\ cosz\ cosh$ or $Qre = A\ \alpha\ I\ cosz\ cosh$

Analysis to the south

The cathetus that is perpendicular to the south wall is Y, therefore:

$senz = Y/I$ therefore $Y = I\ senz$

$cosz = X/I$ therefore $X = I\ cosz$

With respect to the solar height, it is observed that the cathetus that is perpendicular to the south wall is A and the value of the irradiation I will be Isenz, therefore:

$senh = B/Isenz$ therefore $B = I\ senz\ senh$

$cosh = A/Isenz$ therefore $A = I\ senz\ cosh$

The formulae to be used for the south façade will be:

$Qrs = A\ \alpha\ I\ senz\ cosh$ or $Qrs = A\ \tau\ I\ senz\ cosh$

Analysis for the roof

The leg that is perpendicular to the roof is M, therefore:

$senh = M/I$ therefore $M = I\ senh$

$cosh = L/I$ therefore $L = I\ cosh$

The formulae to be used for the roof will be:

$Qrt = A\ \tau\ I\ senh$ or $Qrt = A\ \alpha\ I\ senh$

Applying to the conditions of the two-storey house and considering the areas in table 9, we have:

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January. Solar height of 48°, azimuth of 20° SE, irradiation of 5300 Wh and 11.1 hours of sunshine.

Ground floor

To the east there are 3 m^2 of windows and 31.70 m^2 of wall, therefore:

Heat from windows to the east = $A\,\tau\,I\,cosz\,cosh$ = (3m^2) (0.8) (477.48) (cos20°) (cos48°)

Heat from windows to the east = 720.54 W

Heat from walls to the east = $A\,\alpha\,I\,cosz\,cosh$ = (31.70m^2) (0.8) (477.48) (cos20°) (cos48°)

Heat from walls to the east = 7,614.70 W

Heat to this ground floor = 8,335.24 W

To the south it has 8.5 m^2 of windows, 3.9 m^2 of wooden doors and 28.4 m^2 of walls, therefore:

Heat from windows to the south = $A\,\tau\,I\,senz\,cosh$ = (8.5m^2) (0.8) (477.48) (sen20°) (cos48°)

Heat from windows to the south = 743.06 W

Heat from doors to the south = $A\,\alpha\,I\,senz\,cosh$ = (3.9m^2) (0.8) (477.48) (sen20°) (cos48°)

Heat from doors to the south = 340.93 W

Heat from walls to the south = $A\,\alpha\,I\,senz\,cosh$ = (28.4m^2) (0.8) (477.48) (sen20°) (cos48°)

Heat from walls to south = 2,482.70 W

Heat from south ground floor = 3,566.69 W

Total radiant heat gain = 11,901.93 W.

First level

To the east there are 5.5 m^2 of windows and 29.20 m^2 of wall, therefore:

Window heat to the east = $A\,\tau\,I\,cosz\,cosh$ = (5.5m^2) (0.8) (477.48) (cos20°) (cos48°)

Window heat to the east = 1,321.00 W

Heat from windows to the east = $A\,\alpha\,I\,cosz\,cosh$ = (29.20m^2) (0.8) (477.48) (cos20°) (cos48°)

Heat from walls to the east = 7,014.24 W

Heat to this ground floor = 8,335.24 W

To the south it has 9.8 m^2 of windows and 31 m^2 of walls, therefore:

Heat from windows to the south = $A\,\tau\,I\,senz\,cosh$ = (9.8m^2) (0.8) (477.48) (sen20°) (cos48°)

Heat from windows to south = 856.71 W

Heat from walls to the south = $A\,\alpha\,I\,senz\,cosh$ = (31m^2) (0.8) (477.48) (sen20°) (cos48°)

Heat from walls to the south = 2,709.99 W

Heat to south ground floor = 3,566.69 W

The roof is 245.82 m^2 and has no domes, therefore:

Roof heat = $A\,\alpha\,I\,senh$ = (245.82m^2) (0.8) (477.48) (sen48°)

Roof heat = 69,780.54 W

Total heat gain from solar radiation = 81,682.47 W.

April. Solar height of 74° solar height, azimuth of 29° ES, irradiance of 7400 Wh and 12.6 hours of sunshine.

Ground floor

To the east there are 3 m^2 of windows and 31.70 m^2 of wall, therefore:

Heat from windows to the east = $A\,\tau\,I\,cosz\,cosh$ = (3m^2) (0.8) (587.3) (cos29°) (cos74°)

Heat from windows to the east = 339.80 W

Heat from walls to the east = $A\,\alpha\,I\,cosz\,cosh$ = (31.70m^2) (0.8) (587.3) (cos29°) (cos74°)

Heat from walls to the east = 3,591.02 W

Heat to the east ground floor = 3,930.82 W.

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South has 8.5 m^2 of windows, 3.9 m^2 of wooden doors and 28.4 m^2 of walls, therefore:

Heat from windows to the south = $A\,\tau\,I\,senz\,cosh$ = (8.5m^2) (0.8) (587.3) (sen29°) (cos74°)

Heat from windows to the south = 533.67 W

Heat from doors to the south = $A\,\alpha\,I\,senz\,cosh$ = (3.9m^2) (0.8) (587.3) (sen29°) (cos74°)

Heat from doors to the south = 244.86 W

Heat from walls to the south = $A\,\alpha\,I\,senz\,cosh$ = (28.4m^2) (0.8) (587.3) (sen29°) (cos74°)

Heat from walls to the south = 1,783.10 W

Heat from doors to south = 2,561.63 W

Total radiant heat gain = 6,492.45 W.

First level

To the east there are 5.5 m^2 of windows and 29.20 m^2 of wall, therefore:

Heat from windows to the east = $A\,\tau\,I\,cosz\,cosh$ = (5.5m^2) (0.8) (587.3) (cos29°) (cos74°)

Heat from windows to the east = 622.97 W

Heat from walls to the east = $A\,\alpha\,I\,cosz\,cosh$ = (29.20m^2) (0.8) (587.3) (cos29°) (cos74°)

Heat from walls to the east = 3,307.85 W

Heat to the east ground floor = 3,930.82 W

To the south it has 9.8 m^2 of windows and 31 m^2 of walls, therefore:

Heat from windows to the south = $A\,\tau\,I\,senz\,cosh$ = (9.8m^2) (0.8) (587.3) (sen29°) (cos74°)

Heat from windows to the south = 615.29 W

Heat from walls to the south = $A\,\alpha\,I\,senz\,cosh$ = (31m^2) (0.8) (587.3) (sen29°) (cos74°)

Heat from walls south = 1,946.34 W

Heat to the south ground floor = 2,561.63 W

The roof has 245.82 m^2 and no domes, therefore:

Roof heat = $A\,\alpha\,I\,senh$ = (245.82m^2) (0.8) (587.3) (sen74°)

Roof heat = 111,022.34 W

Total radiant heat gain = 117,514.80 W.

Table 12 presents the results obtained for each level of the house.

Table 13 shows the results of the heat balance for the house, including the air flow required by the equipment.

	January		April	
	Ground floor	**First level**	**Ground floor**	**First level**
East window	720.54	1,321.00	339.80	622.97
East wall	7,614.70	7,014.24	3,591.02	3,307.85
Total east W	**8,335.24**	**8,335.24**	**3,930.82**	**3,930.82**
South window	743.06	856.71	533.67	615.29
South door	340.93	0	244.86	0
South Wall	2,482.70	2,709.99	1,783.10	1,946.34
Total South W	**3,566.69**	**3,566.69**	**2,561.63**	**2,561.63**
Total Roof W	**0**	**69,780.54**	**0**	**111,022.34**
Total radiation W	**11,901.93**	**81,682.47**	**6,492.45**	**117,514.80**

Table 12 Total radiation (W) per dwelling level
Source: Own elaboration

	January		April	
	Ground floor	**First level**	**Ground floor**	**First level**
Occupants W	558.12	558.12	558.12	558.12
Equipment W	2256.741	745.254	2256.741	745.254
Environment W	-3988.62	-10523.29	306.82	809.48
Radiation W	11901.93	81682.47	6492.45	117514.80
Total kW	**10.73**	**72.46**	**9.61**	**119.63**
Tons of cooling TR	**3.05**	**20.60**	**2.73**	**34.02**
Required air flow Kg/s	**1.98**	**13.35**	**2.28**	**28.34**

Table 13 Heat balance results
Source: Own elaboration

Strategies to reduce the sensible heat load of the dwelling.

a) Thermal insulation of the envelope and use of coatings

The results in table 13 show the use of air conditioning equipment for each floor of the dwelling. This can be a single unit housed on the roof and using ductwork to carry the air flow to the different spaces in the dwelling, or, more advisable, using several units. By using the latter option, it is possible to switch on only the equipment that is required at that moment and allows greater heat exchange due to cross ventilation.

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To reduce the sensible heat load obtained in the heat balance of the dwelling, some strategies can be used to avoid and reduce the passage of unwanted heat flow, for example, from table 13 we can see that solar radiation has the greatest impact on heat input, followed by the interaction of the envelope with the environment, for which some recommendations can be made:

To reduce the heat flow through the walls and roofs, additional coatings can be used, either by increasing the thickness of the plaster or even adding another material, for example, in some houses the walls are covered with wood or tiles, or in the case of the roof, in addition to increasing the thickness of the plaster, a brickwork can be used on the outside, which increases the thermal resistance of the envelope. In the case of windows, double-glazed windows can be used, which would increase their thermal resistance and dampen any variations in ambient temperature that may occur.

In the case of solar radiation, the roof is the element with the greatest heat gain, so it is necessary to insulate it. For example, Roof Mastic® acrylic insulation and waterproofing from Comex can be used, which has a reflectance of 0.83 to 0.85, thermal emittance of 0.89 to 0.90 and thermal conductivity of 0.99 to 0.10 W/m°K. For the case of walls, reflective paints such as Doal can be used, which has a reflectance of 0.87. Table 14 shows the results of using any of the strategies presented above.

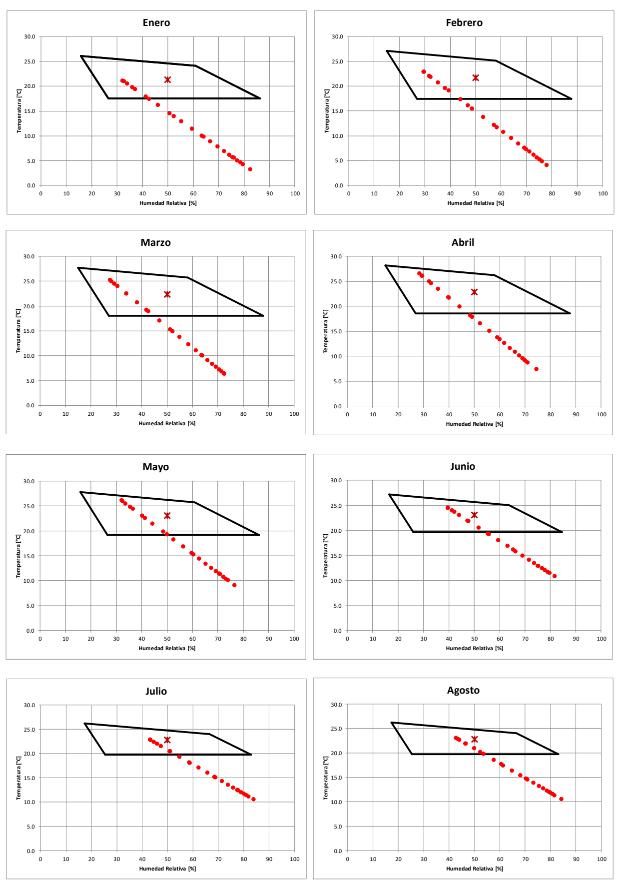
	January		April	
	Ground floor	First level	Ground floor	First level
Occupants W	558.12	558.12	558.12	558.12
Equipment W	2256.741	745.254	2256.741	745.254
Environment W	-2873.13	-8821.39	221.01	678.57
Radiation W	3159.83	17714.00	1786.56	24296.54
Total kW	**3.10**	**10.20**	**4.82**	**26.28**
Tons of cooling TR	**0.88**	**2.90**	**1.37**	**7.47**
Required air flow Kg/s	**0.57**	**1.88**	**1.14**	**6.23**
Savings in KW	**7.63**	**62.27**	**4.79**	**93.35**
Savings in %	**71.09**	**85.93**	**49.84**	**78.03**
Kg of CO_2 saved	**3.23**	**26.34**	**2.03**	**39.49**

Table 14 Results obtained when applying the thermal insulation strategies with coatings
Source: Own elaboration

The Energy Regulatory Commission has notified that the electricity emission factor of the National Electricity System for the calculation of indirect greenhouse gas emissions from electricity consumption for the year 2021 is 0.423 tCO2e / MWh. Table 16 shows that by increasing the flatness of the walls, painting them with a reflective coating, installing double-glazed windows, increasing the flatness of the roof, as well as painting it with a reflective coating, a reduction in the sensible load of the building can be achieved, providing energy savings for space heating and cooling.

b) Passive techniques

The bioclimatic study was carried out on the basis of Olgyay's bioclimatic diagrams (Olgyay, 1963), adapted to the site, with the central comfort temperatures, the average ambient temperature for each month and considering 50% relative humidity. Figure 8 shows the Olgyay diagrams for Presa la Concepción.



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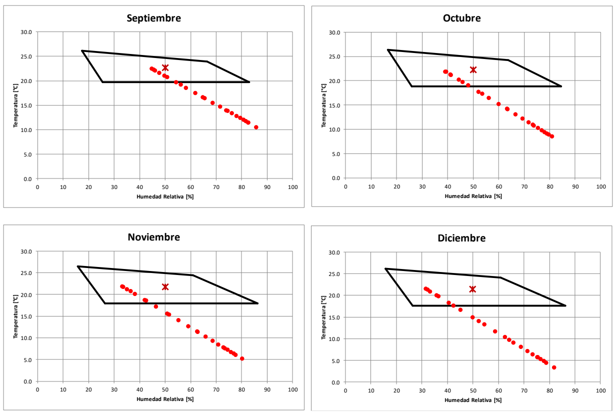

Figure 8 Olgyay bioclimatic diagrams, for each month of Presa la Concepción
Source: Own elaboration with Biosol software (Preciado, 2010)

With the statistical data of the site, the thermal conditions of the site can be determined, where the hours of the day when it is cold, hot or thermally comfortable can be seen. Bioclimatic design strategies and recommendations for passive climate control systems will be made based on this information, which is presented in Figure 9.

Tepotzotlan,EMx												
HORA/MES	ENERO	FEBRERO	MARZO	ABRIL	MAYO	JUNIO	JULIO	AGOSTO	SEPTIEMBRE	OCTUBRE	NOVIEMBRE	DICIEMBRE
00:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
01:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
02:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
03:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
04:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
05:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
06:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
07:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
08:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
09:00	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1
10:00	-1	-1	0	0	0	0	0	0	-1	-1	-1	-1
11:00	-1	0	0	0	0	0	0	0	0	0	0	-1
12:00	0	0	0	0	0	0	0	0	0	0	0	0
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16:00	0	0	0	0	0	0	0	0	0	0	0	0
17:00	0	0	0	0	0	0	-1	-1	-1	0	0	0
18:00	-1	-1	0	0	0	-1	-1	-1	-1	-1	-1	-1
19:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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21:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
22:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
23:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

-1 FRÍO 0 CONFORT 1 CALOR

Figure 9 Bioclimate in Presa de Concepción, State of Mexico
Source: Own elaboration with Biosol software (Preciado, 2010)

Figure 9 shows that in the months of January and December it is predominantly cold, between March and June it is predominantly comfortable during the day and in the months of February and from July to November it is cool in the mornings and evenings. In these situations, the strategies for the three conditions would be heating during the cold and cool months, in the latter case only in the mornings, and ventilating during the day in the comfort months.

Ventilation can be cross ventilation, unilateral and with warm air discharged through the roof, as well as reinforced by solar chimneys, shaded spaces or spaces with pressure differential, such as a shaded central courtyard, or with fountains and water features.

For passive heating, windows should allow direct solar radiation to enter, double glazing is recommended to avoid heat loss during the night and can be reinforced with a window greenhouse, remembering that it can modify the temperature, humidity and odour of the room where it is located. Windows should have eaves designed to allow heat to enter in the mornings and afternoons, preventing it from entering during the hours when there is thermal comfort. The recommended passive systems can be found in depth in the book Bioclimatica by Morillon (1993).

According to figure 4, the east and west sides have the largest number of windows, so it will be necessary to protect them, especially those on the first level where cooling is required. This can also be controlled by means of curtains, for example, if heating is required, these should be opened, otherwise they should be closed to avoid direct heat gain.

It is also possible to take advantage of the wind and channel a flow of air to remove the heat that is inside the building, specifically from the first level. According to figure 1, the predominant wind directions during the year are east and west, which is ideal for the building due to its design, it is only necessary to allow it to enter through vents in walls or through the windows themselves.

Conclusion

The use of coatings, thermal insulation, passive systems and the use of the sun and wind are strategies that allow us to achieve the comfort conditions of a building, without the use of conventional air conditioning systems that consume too much energy. This allows us to save energy, which leads to a reduction in our energy bills and a reduction in fuel consumption and greenhouse gas emissions.

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Article **Journal Architecture and Design**
June 2022, Vol.6 No.15 1-12

Acknowledgements

We are grateful to the Internal Research Chairs Programme (FES Cuautitlán - UNAM) for the support provided through project CI2252.

We are grateful to the Programa de Apoyo a Proyectos para la Innovación y Mejoramiento de la Enseñanza (PAPIME-UNAM), for the support provided through project PE100222.

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