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Journal of Architecture and Design

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Knowledge Area

The works must be unpublished and refer to issues of international architecture, technological innovation in architecture, industrial design, business design techniques, multimedia design, advertising design, web system design, residential architecture and other topics related to Engineering Sciences and Technology.

Presentation of the Content

In Issue 15, is presented an article *Strategies for passive air conditioning and energy saving of a house considering the bioclimate of the place, by* HERNÁNDEZ-GÓMEZ, Víctor Hugo, MORILLÓN-GÁLVEZ, David, OLVERA-GARCÍA, Omar and GUZMAN-TINAJERO, Pedro, with adscription at Universidad Nacional Autónoma de México, in the next article *Analysis of thermal comfort by simulation for a house with poured concrete construction system for a hot-dry climate*, by CAMACHO-IXTA, Ixchel Astrid, DELGADO-RENDON, Rene, GONZÁLEZ-DURÁN, Mario and LÓPEZ-LAMBRAÑO, Álvaro Alberto, with adscription at Universidad Autónoma de Baja California, in the next section *Organic addition for mortar mixtures based on pitahaya cactus*, by DÍAZ-FLOTA, Oscar Santiago, YELADAQUI-TELLO, Alberto, CRUZ-ARGÜELLO, Julio César and GURROLA Mayra Polett, with adscription at Instituto Tecnológico de Chetumal and CONACYT-Tecnológico Nacional de México - Chetumal, in the next section *Implementation of a home automation system to automate the functions of a community centre due to the sanitary measures implemented by the COVID-19 pandemic,* by ECHANDI-PACHECO, Rodolfo, with adscription at Universidad Fidélitas.

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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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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

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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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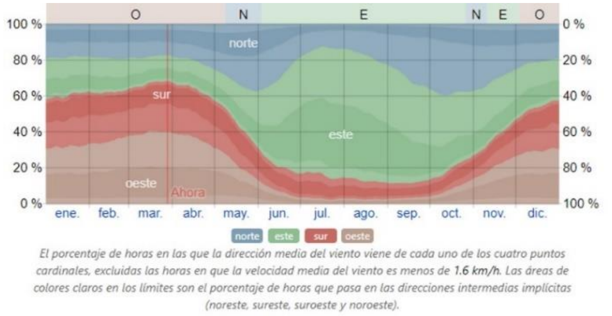

Figure 1 Wind direction in Santiago Cuautlalpan
Source: https://es.weatherspark.com/y/5666/Clima-promedio-en-Santiago-Cuautlalpan-M%C3%A9xico-durante-todo-el-a%C3%B1o

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.

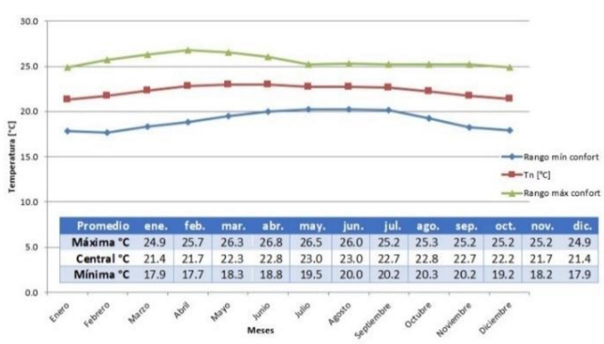

Figure 2 Comfort zone of Presa la Concepción
Source: Own elaboration with Biosol software (Preciado, 2010)

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

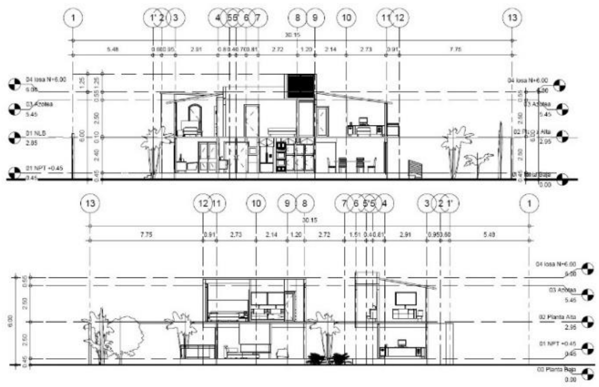

Figure 4 Longitudinal sections of the house
Source: Own elaboration

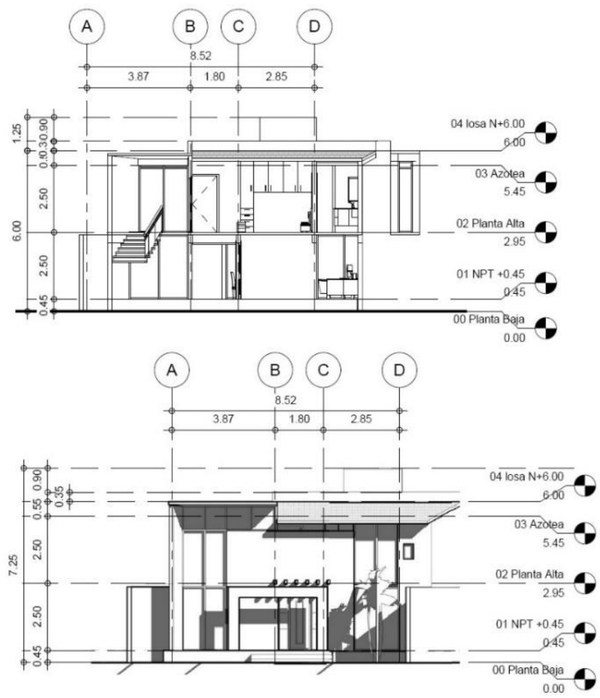

Figure 5 Cross-sections of the dwelling
Source: Own elaboration

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.

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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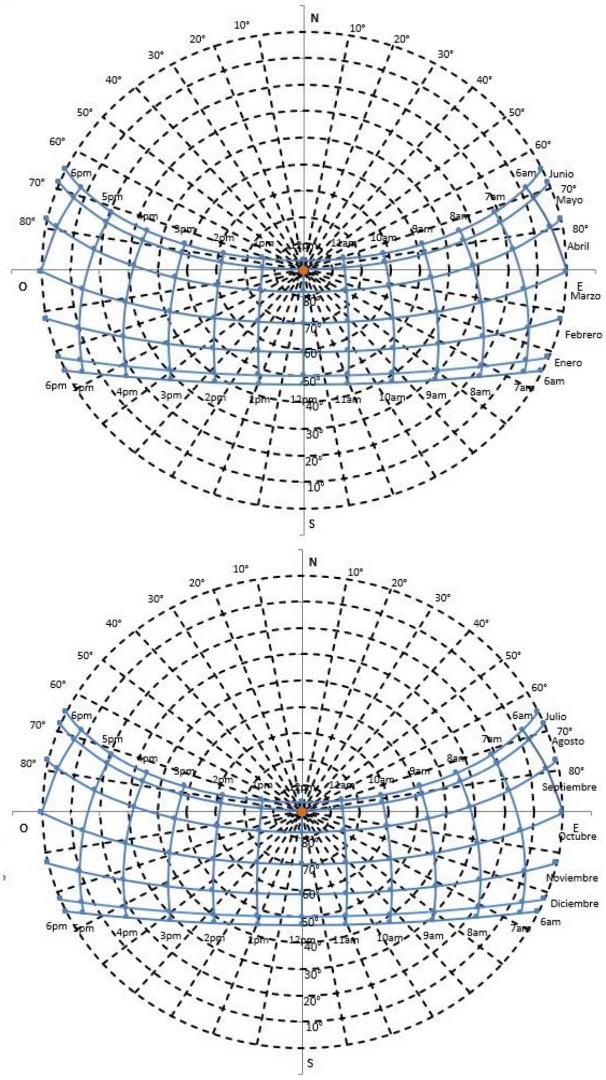

Figure 6 Solar diagrams for Presa la Concepción, latitude 19.69
Source: Own elaboration with Biosol software (Preciado, 2010)

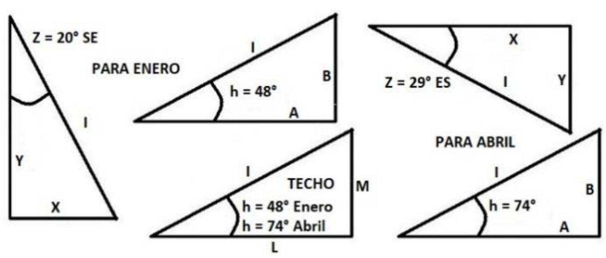

Figure 7 Triangles formed with azimuth z and solar height h for the application case
Source: Own elaboration

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:

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.

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.

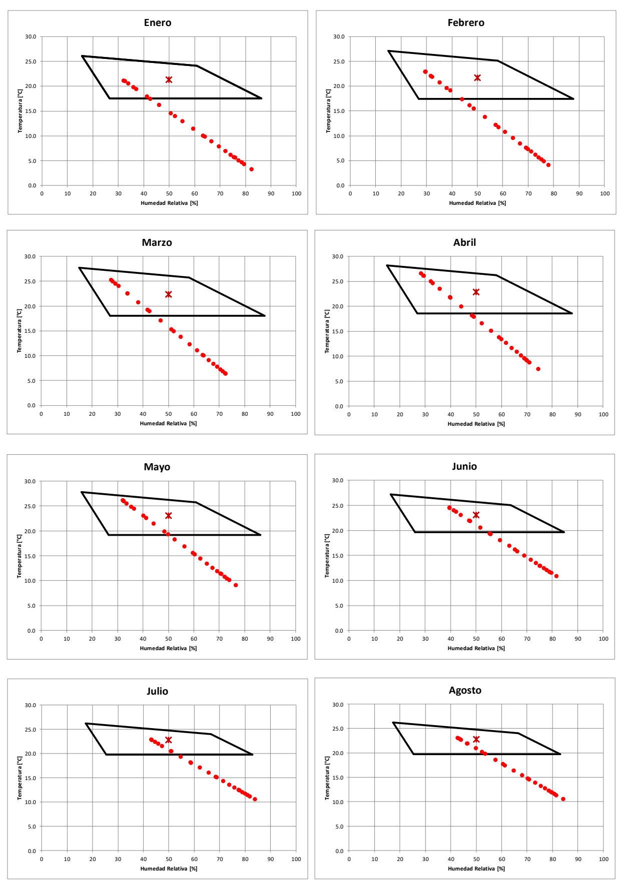
	January		April	
	Ground floor	First level	Ground floor	First level
Occupants W	558.12	558.12	558.12	558.12
Equipment W	2256.741	745.254	2256.741	745.254
Environment W	-2873.13	-8821.39	221.01	678.57
Radiation W	3159.83	17714.00	1786.56	24296.54
Total kW	**3.10**	**10.20**	**4.82**	**26.28**
Tons of cooling 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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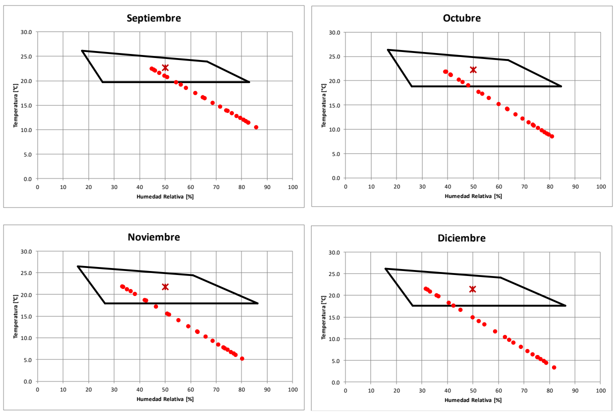

Figure 8 Olgyay bioclimatic diagrams, for each month of Presa la Concepción
Source: Own elaboration with Biosol software (Preciado, 2010)

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
13:00	0	0	0	0	0	0	0	0	0	0	0	0
14:00	0	0	0	0	0	0	0	0	0	0	0	0
15:00	0	0	0	0	0	0	0	0	0	0	0	0
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
20:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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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Analysis of thermal comfort by simulation for a house with poured concrete construction system for a hot-dry climate

Análisis de confort térmico por medio de simulación para una vivienda con sistema constructivo de concreto vaciado para un clima cálido-seco

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Abstract

The objective of this work is to analyze the behavior of internal thermal comfort of low-income housing built with a cast concrete construction system, and determine the effects of strategies that promote the improvement of thermal comfort of the interior environment, specifically in climate environment. Hot-dry, particularly in the Tijuana, Baja California region, considering transitory periods that correspond to the period between hot-cold and cold-warm. Given the selection of the construction system in the region, it has been observed that the house does not meet the needs of thermal comfort inside, consequently in this work the alternatives are simulated to improve the thermal comfort inside the houses in the occupation hours. This simulation was carried out through the Design Builder program, which is based on a case study, which served as you know to validate the simulation model. Proposals for improvement in the home are made in order to analyze its effects on interior thermal comfort, covering from March to April and the month of November. Surface and indoor ambient temperatures were measured on the ceiling and indoor space, respectively.

Simulator, Climate, Thermal Comfort

Resumen

El presente trabajo tiene el objetivo de analizar el comportamiento de confort térmico interno de la vivienda de interés social construida con un sistema constructivo de concreto vaciado, y determinar efectos de medidas que promuevan la mejora del confort térmico del ambiente interior, específicamente en ambiente de clima cálido-seco, de manera particular en la región de Tijuana Baja California, considerando periodos transitorios que corresponden a el periodo entre cálido-frio y frio-cálido. Dada la selección del sistema de construcción en la región, se ha observado que la vivienda no satisface las necesidades de confort térmico a su interior, en consecuencia en este trabajo se simulan las alternativas para mejorar el confort térmico dentro de las viviendas en los horarios de ocupación. Esta simulación se efectúo a través del programa de Design Builder, donde se parte de un caso de estudio, el cual sirvió como sabe para validar el modelo de simulación. Se realizan propuestas de mejora en la vivienda a fin de analizar sus efectos en el confort térmico interior abarcando de marzo a abril y el mes de noviembre. Se midieron temperaturas superficiales y de ambiente interior, en techo y espacio interior respectivamente.

Simulador, Clima, Confort Térmico

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Introduction

Currently the predominant construction systems in the region and specifically in the city of Tijuana correspond to the type of poured concrete system, this has caused the characteristics of this type of housing to present unsatisfied needs of comfort in interior temperature, since in addition to the construction material, the elements of the house do not consider the proper selection of the construction system and materials that contribute to improve the thermal comfort inside the houses. It does not consider the type of climate where they are built, this creates a thermal discomfort to the user that derives from the construction systems and the lack of adaptability to the climate of the region.

This work seeks to demonstrate, by means of simulation in the specialized Design Builder software, that the proposals that imply modifying the envelope with covering material such as thermal insulation with polystyrene and passive shading elements, have positive effects on the ambient temperature inside the building, its control and variability.

Table 1 shows the methodology implemented, which consists of generating a reference model for the simulation, starting from the characterization of a house and the measured data of its thermal behavior in surface and interior environment. Based on this, the model is validated and the simulation is carried out integrating the proposals under conditions of transient periods.

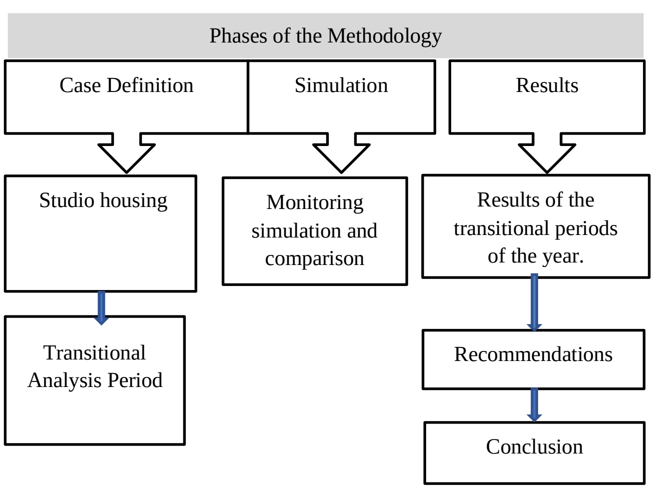

Table 1 Methodology
Source: Own elaboration

Development

Given the excessive growth of the city, there was a need to accelerate the construction of low-income housing (Camacho I, Delgado R., & Bojorquez, 2017) and with it a problem was generated in housing and for the users who inhabit them. And it is that the materials with which they are built (poured concrete) are not the best for hot-dry climates (Sanchez , 2008), given that in Tijuana minimum temperatures have reached 3°C and maximum temperatures in warm period up to 37°C (Camacho I., 2019).

Site zoning

According to Saavedra Lara, the exponential increase in the population of Tijuana, in the 80's there was a wave of migration in Tijuana, after the 1985 earthquake and people from all parts of the republic arrived in the city in search of better opportunities. And that is when the accelerated construction of housing, mainly of social interest, began.

Figure 1 Location of Tijuana Baja California
Source: Own Elaboration

Tijuana (Figure 1) is characterized by a predominantly warm-dry climate, with warm springs and autumns with winds known as santana winds; in other words, the city can experience the four seasons of the year in a single day (IMPLAN, 2005).

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In the region there are vertical and horizontal houses with poured concrete construction systems, and the thermal conductivity is high (1.4 W/m °C) compared to polystyrene, which is commonly used as a thermal insulation material in the building envelope (0.035 W/m °C), which causes the internal ambient temperature of the house to change radically. Since it is built with inadequate material and interior comfort is not prioritized, i.e., it is built without considering the comfort needs of the users, since they will have to condition their homes to improve the interior thermal comfort by investing in modifications to the building.

Figure 2 Study housing in Tijuana Baja California
Source: Own elaboration

Figure 2 shows the reference case, a social interest housing, which is built with a concrete system poured vertically and in series, has a construction area of 63.48 m², for an occupancy of 4 inhabitants, consists of two bedrooms, 1 bathroom and a common area consisting of living room, dining room and kitchen, the orientation in this case has the peculiarity of being out of phase 45 degrees, being the front to the south-east.

Modeling and simulation

In the simulation program Design Builder the thermal characteristics of the materials that make up the house were entered, integrating 1 inch of commercial polystyrene in the envelope since its conductivity is lower than that of concrete and has excellent thermal insulation qualities, the design of the house was made in the software taking into account its orientation and dimensions. The program requires a file with climatological data in epw format (Energy Plus Weather data), which was generated with historical data from the Tijuana stations (CONAGUA, 2010). The simulation allows designing advanced strategies for different envelopes and air conditioning systems to focus them on improving thermal comfort for the benefit of the users.Once the house has been simulated with the proposed conditions, a comparison is made between the simulated and measured conditions in transitional periods 1 (March-April) and transitional period 2 (November), in order to determine the behavior and effects of the proposed modifications to the house, which in turn affect the indoor ambient temperature of the building.

Transient analysis period

The indoor ambient temperature and indoor surface temperature of the roof were considered when monitoring the house. The thermal comfort zone range (Ener-Habitat, 2014) of indoor environment of 21.8°C -24.6°C was also established. Once the housing scenario was modeled together with the measures of covering the envelope with 1 inch of polystyrene as thermal insulation on the roof and walls, and shading with pergola on the windows, the indoor ambient temperature pattern was generated for the transient periods. In the first transitional period of March-April the temperature oscillates from 13°C to 27°C, specifically in the month of March the transition phenomenon is observed with temperature changes in the first half of the month, and the second half with an increase in temperatures inside the house (Table 2). In the second transitional period, the indoor ambient temperature oscillates between 14°C -24°C. Table 3 shows the variation of indoor ambient temperatures, where the transition phenomenon is reflected.

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	Temperaturas Ambiente Interior Horarias (MARZO)															
HORA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
01:00	18.10	17.95	18.30	17.64	16.76	17.68	17.81	17.43	15.81	15.37	14.47	17.09	17.35	14.98	16.02	15.69
02:00	17.87	17.71	17.99	17.29	16.49	17.24	17.50	17.06	15.43	15.14	14.31	16.88	17.11	14.79	15.86	15.57
03:00	17.63	17.46	17.66	16.92	16.23	16.84	17.19	16.69	15.10	14.91	14.16	16.66	16.84	14.65	15.70	15.43
04:00	17.41	17.19	17.31	16.57	15.96	16.49	16.86	16.30	14.79	14.70	14.00	16.41	16.21	14.49	15.54	15.27
05:00	17.18	16.89	16.94	16.25	15.67	16.17	16.49	15.93	14.48	14.49	13.83	16.15	15.64	14.32	15.38	15.08
06:00	16.97	16.59	16.59	15.94	15.38	15.87	16.16	15.59	14.20	14.31	13.67	15.88	15.29	14.16	15.22	14.90
07:00	16.77	16.28	16.29	15.64	15.12	15.60	15.85	15.31	13.97	14.15	13.51	15.63	15.08	14.02	15.07	14.74
08:00	16.67	16.11	16.10	15.46	15.01	15.47	15.72	15.16	13.89	14.01	13.43	15.52	14.91	14.12	15.08	14.67
09:00	16.92	16.36	16.27	15.53	15.32	15.78	16.08	15.31	14.16	14.05	13.62	15.83	14.91	14.73	15.24	14.95
10:00	17.35	16.78	16.62	15.58	15.83	16.30	16.65	15.52	14.43	14.25	13.99	16.29	15.03	15.47	15.56	15.50
11:00	17.80	17.37	17.15	15.73	16.49	17.01	17.36	15.97	14.72	14.66	14.57	16.84	15.21	16.29	15.66	16.05
12:00	18.37	18.13	17.83	16.11	17.26	17.80	18.13	16.50	15.02	15.05	15.26	17.38	15.46	16.96	15.82	16.67
13:00	18.74	18.79	18.51	16.61	17.90	18.45	18.75	17.09	15.48	15.39	15.93	17.85	15.71	17.53	16.09	17.14
14:00	18.96	19.32	19.05	17.24	18.54	18.93	19.19	17.58	15.96	15.64	16.64	18.32	15.97	17.78	16.48	17.58
15:00	19.14	19.78	19.51	17.77	19.17	19.32	19.58	17.94	16.50	15.81	17.40	18.77	16.14	17.80	16.92	17.97
16:00	19.31	20.21	19.87	18.19	19.72	19.61	19.92	18.22	16.95	15.76	18.07	19.11	16.06	17.68	17.27	18.23
17:00	19.39	20.36	19.96	18.33	19.93	19.67	20.02	18.35	17.10	15.77	18.41	19.15	16.08	17.55	17.33	18.40
18:00	19.35	20.25	19.83	18.30	19.85	19.60	19.95	18.28	17.06	15.70	18.48	19.10	16.09	17.40	17.27	18.48
19:00	19.22	19.95	19.57	18.13	19.55	19.39	19.70	18.06	16.86	15.53	18.34	18.87	16.02	17.24	17.15	18.37
20:00	19.04	19.67	19.29	17.92	19.24	19.18	19.40	17.70	16.62	15.34	18.12	18.61	15.93	17.04	17.02	18.19
21:00	18.83	19.43	18.99	17.72	18.96	18.94	19.01	17.29	16.35	15.16	17.89	18.34	15.81	16.82	16.91	18.03
22:00	18.62	19.15	18.68	17.50	18.71	18.68	18.56	16.92	16.11	14.97	17.66	18.10	15.66	16.59	16.59	17.89
23:00	18.41	18.86	18.34	17.28	18.43	18.41	18.16	16.54	15.86	14.79	17.46	17.85	15.50	16.39	16.05	17.74
00:00	18.18	18.58	17.98	17.03	18.09	18.12	17.79	16.18	15.61	14.63	17.27	17.61	15.28	16.19	15.79	17.59
Tmin	16.67	16.11	16.10	15.46	15.01	15.47	15.72	15.16	13.89	14.01	13.43	15.52	14.91	14.02	15.07	14.67
Tmax	19.39	20.36	19.96	18.33	19.93	19.67	20.02	18.35	17.10	15.81	18.48	19.15	17.35	17.80	17.33	18.48

	Temperaturas Ambiente Interior Horarias (MARZO)														
HORA	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
01:00	17.4	21.4	22.3	21.4	19.9	19.7	21.3	21.0	21.3	21.2	20.3	22.6	22.2	19.0	20.3
02:00	17.2	21.2	22.0	21.0	19.5	19.3	21.0	20.7	21.0	20.9	20.0	22.1	21.8	18.7	19.9
03:00	17.1	20.9	21.6	20.7	19.1	18.9	20.6	20.3	20.6	20.5	19.7	21.6	21.5	18.4	19.6
04:00	16.9	20.5	21.2	20.2	18.7	18.6	20.2	20.0	20.2	20.1	19.4	21.1	21.2	18.1	19.3
05:00	16.8	20.0	20.8	19.8	18.3	18.2	19.8	19.7	19.7	19.6	19.1	20.5	20.9	17.8	19.0
06:00	16.7	19.6	20.5	19.3	17.9	17.9	19.3	19.4	19.3	19.2	18.8	20.1	20.6	17.5	18.8
07:00	16.6	19.2	20.1	19.0	17.6	17.7	19.0	19.2	19.0	18.9	18.6	19.8	20.3	17.3	18.7
08:00	16.8	19.3	20.2	19.0	17.8	17.9	19.2	19.4	19.2	19.0	18.9	19.9	20.2	17.5	19.0
09:00	17.3	19.5	20.3	19.2	18.1	18.4	19.5	19.8	19.5	19.2	19.3	20.2	20.2	17.8	19.4
10:00	17.8	20.0	20.7	19.5	18.6	19.0	20.0	20.3	20.0	19.6	20.0	20.7	20.3	18.4	20.1
11:00	18.6	20.7	21.2	19.8	19.4	19.8	20.7	21.0	20.6	20.2	20.9	21.4	20.6	19.2	21.0
12:00	19.2	21.4	21.9	20.3	20.2	20.6	21.5	21.7	21.4	20.9	21.8	22.3	20.9	20.1	21.8
13:00	19.9	22.1	22.5	20.8	21.0	21.2	22.0	22.2	21.9	21.5	22.4	23.0	21.1	20.7	22.5
14:00	20.7	22.8	23.0	21.4	21.6	21.8	22.5	22.6	22.4	21.9	23.2	23.4	21.4	21.4	23.4
15:00	21.4	23.4	23.5	21.8	22.2	22.4	22.9	23.1	22.9	22.3	23.9	23.9	21.6	22.1	24.1
16:00	21.9	24.0	23.9	22.1	22.7	23.0	23.2	23.4	23.3	22.5	24.5	24.2	21.5	22.6	24.7
17:00	22.3	24.3	24.0	22.2	22.7	23.2	23.3	23.5	23.4	22.6	24.7	24.4	21.0	22.8	24.9
18:00	22.4	24.3	23.9	22.1	22.6	23.3	23.2	23.4	23.3	22.6	24.8	24.4	20.5	22.7	25.0
19:00	22.4	24.1	23.7	21.9	22.3	23.0	23.0	23.1	23.1	22.4	24.6	24.1	20.0	22.4	24.8
20:00	22.3	23.8	23.4	21.6	22.0	22.7	22.7	22.8	22.8	22.1	24.3	23.9	19.8	22.0	24.5
21:00	22.1	23.5	23.0	21.3	21.6	22.4	22.3	22.5	22.5	21.8	24.0	23.6	19.7	21.7	24.2
22:00	21.9	23.2	22.6	21.0	21.1	22.2	22.0	22.2	22.2	21.4	23.7	23.2	19.5	21.4	23.9
23:00	21.8	23.0	22.2	20.7	20.6	21.9	21.6	21.9	21.9	21.1	23.4	22.9	19.4	21.1	23.6
00:00	21.6	22.7	21.8	20.3	20.2	21.6	21.3	21.6	21.6	20.7	23.0	22.5	19.2	20.7	23.3
Tmin	16.6	19.2	20.1	19.0	17.6	17.7	19.0	19.2	19.0	18.9	18.6	19.8	19.2	17.3	18.7
Tmax	22.4	24.3	24.0	22.2	22.7	23.3	23.3	23.5	23.4	22.6	24.8	24.4	22.2	22.8	25.0

Table 2 Analysis of cold-warm period

Source: Own elaboration

	Temperaturas Ambiente Interior Horarias (NOVIEMBRE)														
HORA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
01:00	20.08	16.70	17.75	16.01	17.11	16.75	17.63	19.35	20.96	22.30	20.96	22.70	20.41	19.09	19.70
02:00	19.74	16.38	17.55	15.75	16.91	16.54	17.34	19.07	20.74	22.15	20.91	22.50	20.09	18.82	19.45
03:00	19.38	16.06	17.31	15.52	16.67	16.32	17.06	18.80	20.51	22.00	20.89	22.28	19.81	18.53	19.20
04:00	18.99	15.75	17.06	15.29	16.40	16.09	16.81	18.52	20.27	21.87	20.85	22.01	19.56	18.18	18.93
05:00	18.58	15.45	16.79	15.03	16.17	15.83	16.53	18.25	20.02	21.73	20.79	21.71	19.29	17.83	18.63
06:00	18.16	15.14	16.57	14.78	15.97	15.56	16.25	18.01	19.73	21.59	20.71	21.44	19.04	17.49	18.32
07:00	17.75	14.85	16.35	14.53	15.77	15.31	15.99	17.77	19.44	21.45	20.63	21.16	18.85	17.22	18.05
08:00	17.42	14.65	16.21	14.38	15.59	15.17	15.87	17.67	19.30	21.34	20.57	20.96	18.71	17.09	17.84
09:00	17.35	14.86	16.01	14.56	15.58	15.38	16.24	18.00	19.61	21.26	20.64	20.95	18.81	17.33	17.85
10:00	17.45	15.31	15.74	14.96	15.74	15.77	16.84	18.54	20.14	20.99	20.90	21.10	19.08	17.80	18.05
11:00	17.79	15.98	15.80	15.60	16.12	16.34	17.63	19.28	20.85	20.93	21.35	21.43	19.49	18.50	18.44
12:00	18.24	16.77	16.17	16.34	16.61	16.99	18.55	20.11	21.66	21.17	21.83	21.83	20.03	19.27	18.96
13:00	18.73	17.52	16.65	17.04	17.05	17.65	19.29	20.78	22.29	21.60	22.31	22.22	20.53	20.02	19.60
14:00	19.13	18.12	17.06	17.54	17.42	18.17	20.01	21.44	22.81	22.01	22.80	22.56	20.91	20.60	20.16
15:00	19.41	18.57	17.38	17.99	17.67	18.67	20.66	22.03	23.25	22.34	23.20	22.83	21.16	21.12	20.59
16:00	19.64	18.99	17.54	18.39	17.86	19.12	21.20	22.48	23.52	22.50	23.50	22.88	21.21	21.57	20.95
17:00	19.60	19.09	17.56	18.51	17.90	19.25	21.30	22.55	23.57	22.56	23.59	22.79	21.14	21.64	21.02
18:00	19.28	18.92	17.47	18.35	17.82	19.05	21.06	22.33	23.39	22.54	23.55	22.61	20.93	21.36	20.82
19:00	18.89	18.74	17.31	18.17	17.72	18.84	20.75	22.10	23.18	22.50	23.47	22.36	20.67	21.08	20.57
20:00	18.49	18.58	17.15	18.00	17.62	18.66	20.49	21.90	23.00	22.40	23.37	22.05	20.40	20.83	20.35
21:00	18.13	18.43	16.96	17.83	17.50	18.51	20.28	21.72	22.87	22.02	23.25	21.74	20.13	20.62	20.07
22:00	17.76	18.29	16.75	17.68	17.33	18.36	20.08	21.55	22.74	21.78	23.12	21.41	19.86	20.41	19.77
23:00	17.39	18.11	16.52	17.50	17.15	18.16	19.89	21.37	22.60	21.54	22.97	21.07	19.58	20.19	19.46
00:00	17.03	17.94	16.27	17.31	16.96	17.91	19.64	21.17	22.45	21.17	22.83	20.73	19.34	19.95	19.17
Tmin	17.03	14.65	15.74	14.38	15.58	15.17	15.87	17.67	19.30	20.93	20.57	20.73	18.71	17.09	17.84
Tmax	20.08	19.09	17.75	18.51	17.90	19.25	21.30	22.55	23.57	22.56	23.59	22.88	21.21	21.64	21.02

	Temperaturas Ambiente Interior Horarias (NOVIEMBRE)														
HORA	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
01:00	18.89	20.16	18.85	18.16	21.03	21.93	21.09	20.91	20.99	18.04	18.57	19.98	19.71	17.48	16.59
02:00	18.63	19.94	18.61	17.97	20.78	21.65	20.82	20.65	20.72	17.73	18.30	19.73	19.45	17.24	16.34
03:00	18.34	19.72	18.35	17.77	20.52	21.34	20.54	20.37	20.43	17.41	18.04	19.47	19.18	16.98	16.09
04:00	18.01	19.50	18.11	17.57	20.25	21.01	20.23	20.10	20.15	17.09	17.78	19.20	18.89	16.70	15.80
05:00	17.62	19.28	17.84	17.35	19.96	20.63	19.92	19.82	19.86	16.77	17.50	18.94	18.57	16.41	15.49
06:00	17.26	19.07	17.59	17.16	19.67	20.25	19.63	19.56	19.58	16.45	17.24	18.67	18.24	16.14	15.18
07:00	16.95	18.85	17.36	16.99	19.44	19.94	19.38	19.34	19.28	16.17	17.01	18.42	17.91	15.88	14.88
08:00	16.82	18.69	17.20	16.91	19.31	19.71	19.23	19.19	19.01	15.95	16.89	18.27	17.62	15.67	14.71
09:00	17.12	18.73	17.20	17.26	19.54	19.80	19.42	19.31	18.84	16.12	17.17	18.46	17.54	15.71	14.92
10:00	17.71	18.82	17.33	17.88	20.03	20.17	19.85	19.70	18.73	16.59	17.70	18.87	17.58	16.00	15.29
11:00	18.50	19.07	17.61	18.70	20.67	20.76	20.46	20.30	18.58	17.29	18.43	19.40	17.83	16.53	15.89
12:00	19.45	19.45	18.01	19.64	21.44	21.46	21.18	20.98	18.62	18.09	19.28	20.04	18.24	17.11	16.56
13:00	20.26	19.86	18.46	20.42	22.09	22.17	21.87	21.59	18.76	18.90	20.04	20.63	18.77	17.68	17.29
14:00	20.89	20.23	18.87	21.18	22.59	22.73	22.38	22.09	18.90	19.54	20.60	21.08	19.22	18.13	17.88
15:00	21.43	20.48	19.21	21.85	23.05	23.10	22.73	22.44	19.28	19.99	21.12	21.40	19.60	18.47	18.29
16:00	21.85	20.58	19.33	22.38	23.43	23.37	22.98	22.69	19.69	20.37	21.52	21.63	19.84	18.66	18.62
17:00	21.88	20.56	19.31	22.56	23.52	23.37	22.96	22.70	19.80	20.40	21.59	21.61	19.78	18.61	18.63
18:00	21.61	20.43	19.19	22.42	23.30	23.07	22.71	22.54	19.63	20.15	21.35	21.38	19.49	18.35	18.40
19:00	21.33	20.24	19.07	22.21	23.09	22.79	22.46	22.37	19.43	19.90	21.13	21.17	19.15	18.08	18.19
20:00	21.10	20.02	18.94	21.99	22.91	22.50	22.22	22.23	19.23	19.72	20.94	20.94	18.82	17.80	18.03
21:00	20.92	19.78	18.78	21.80	22.75	22.20	21.96	22.04	19.04	19.53	20.77	20.68	18.49	17.55	17.85
22:00	20.76	19.56	18.63	21.63	22.60	21.91	21.69	21.82	18.83	19.30	20.62	20.44	18.20	17.29	17.64
23:00	20.57	19.33	18.48	21.45	22.40	21.62	21.43	21.58	18.60	19.05	20.43	20.20	17.96	17.06	17.43
00:00	20.38	19.10	18.33	21.28	22.17	21.35	21.16	21.28	18.34	18.81	20.22	19.95	17.72	16.83	17.20
Tmin	16.82	18.69	17.20	16.91	19.31	19.71	19.23	19.19	18.34	15.95	16.89	18.27	17.54	15.67	14.71
Tmax	21.88	20.58	19.33	22.56	23.52	23.37	22.98	22.70	20.99	20.40	21.59	21.63	19.84	18.66	18.63

Table 3 Warm-cold transient analysis

Source: Own elaboration

Results of the transient periods of the year

In the simulations, the implementation of air conditioning mechanisms was not considered in the house so that the user is in comfort; however, it was determined that passive systems (cross ventilation) and polystyrene envelope are used.

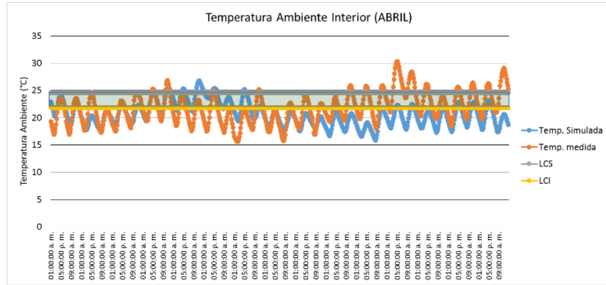

Figure 3 Comparative graph of simulation and monitoring in transitional period 1, April

Source: own elaboration

As part of the transient period 1 of April, the behavior of ambient temperature inside the house with more hours within the comfort zone is presented. A range 16 ºC to 27 ºC of indoor ambient temperature variation is observed, a schedule within comfort in approximately half of the days of the month varying from 10:00 am where they enter comfort and some days leave comfort until 05:00 am. The range of indoor ambient temperature and the frequency with which comfort entry occurs results in a period requiring little shelter to compensate for temperatures below the comfort zone (Figure 3).

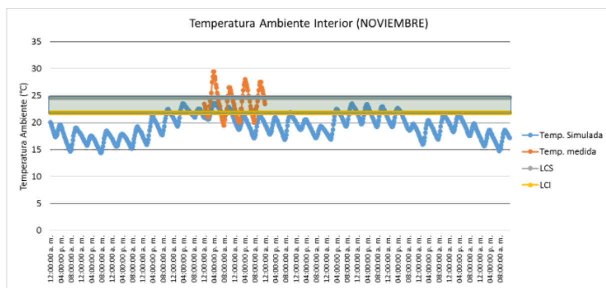

Figure 4 Comparative graph of simulation and monitoring in transitional period 2, November

Source: own elaboration

The month of November (Figure 4) presents a transitory phenomenon, which shows a variation behavior of indoor ambient temperatures in different days and weeks of the month, highlighting a slight tendency to decrease indoor ambient temperatures as it approaches the winter period.

The thermal comfort zone in indoor ambient temperature is from 21.8 ºC to 24.6 ºC, based on this there are fewer hours of the month within the comfort zone, and the vast majority presents indoor ambient temperatures below the comfort zone with minimum values close to 15 ºC, it is highlighted that there are no temperatures that exceed the upper limit of the comfort zone. The days that present temperatures within the comfort zone do so during afternoon hours, after noon, between 13:00 pm and 02:00 am, with the hours 16:00 pm to 20:00 pm coinciding most of these days.

It should be noted that during this period, the measured data corresponds to only one week due to problems with the measurement equipment; however, during the rest of the year, the data obtained allowed generating the base model for the simulation.

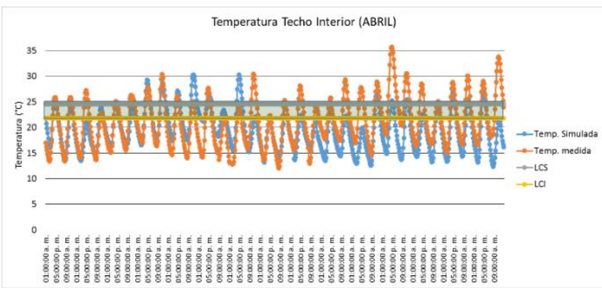

Figure 5 Comparative graph of simulation and monitoring in transitional period 1 in roof
Source: Own elaboration

As shown in Figure 5, the behavior of the temperature measured inside the ceiling reaches values higher than 35 ºC and varies in a wider range than in the case of the ceiling simulated with 1 inch thick polystyrene, highlighting that by insulating the ceiling a better thermal stability is obtained inside the building and therefore a temperature within the comfort zone and more pleasant in terms of thermal sensation can be maintained for a longer period of time.

He also observed a tendency to increase the temperature measured on the roof, which is due to the approaching warm period and where the effect of the insulating material becomes more relevant.

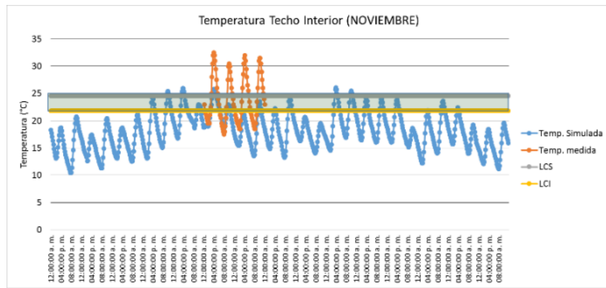

Figure 6 Comparative graph of simulation and monitoring in transitional period 2 in roof
Source: own elaboration

In Figure 6, the temperature behavior inside the roof reaches values higher than 25.74 ºC and varies in a smaller range than in the case of the graph of the first transient period 1 (Figure 5).

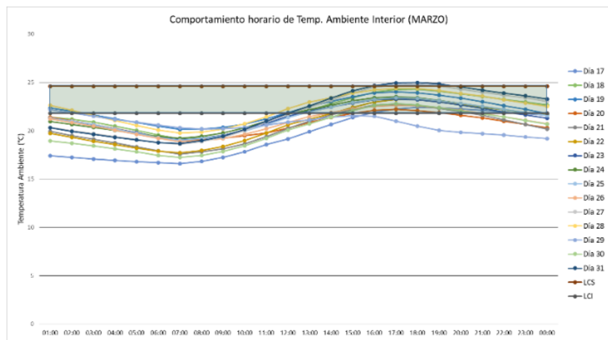

Figure 7 Comparative graph of simulation and hourly behavior, transient period 1 in indoor environment (March)
Source: own elaboration

In Figure 7, from March 17 to 31, there is a maximum of up to 15 hrs in comfort for one day, and an average of 8.8 hrs in comfort in that period, which is equivalent to a maximum of 62.5% of hrs in comfort and an average of 36.6% of the average time per day. It should be noted that from 1 to 16 there are no indoor ambient temperatures within the comfort zone. This allows highlighting the transient effect that occurs and the relevance of the effect of the covering material (thermal insulation) in the envelope. During the whole month of March, only 17.7% of the indoor ambient temperatures are within the comfort zone, 0.94% of the time is above the comfort zone and mostly 81.3% has indoor ambient temperatures below the comfort zone, which translates into a need for heating, which can be achieved by tucking in or by heating.

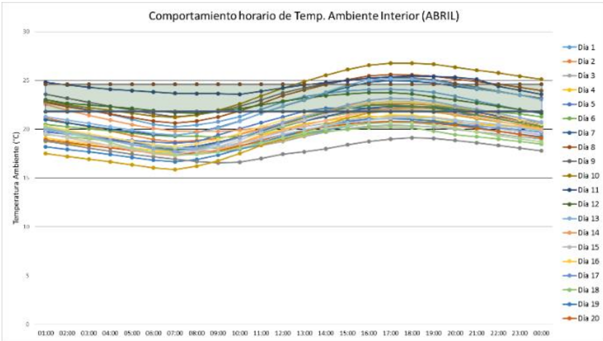

Figure 8 Comparative graph of simulation and hourly behavior, transient period 1 in indoor environment (April)
Source: Own elaboration

In Figure 8, the month of April shows 169 hrs where the indoor ambient temperature is within the comfort zone, equivalent to 23.4% of the time during the whole month of April. As in March, indoor ambient temperatures below the comfort zone predominate, representing 70.4% of the time, and only 6.1% of the time there are indoor ambient temperatures above the comfort zone. It should be noted that there are days with a large number of hours with temperatures within the comfort zone (up to 87.5% of the time that day).

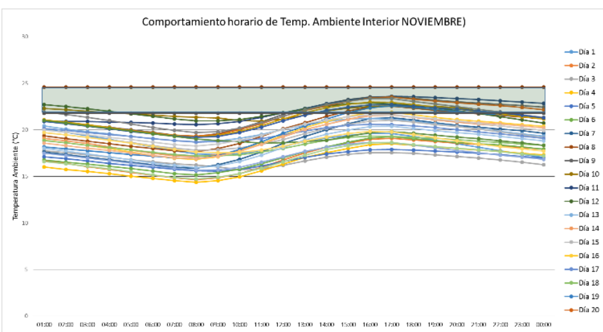

Figure 9 Comparative graph of simulation and hourly behavior, transient period 1 in indoor environment (NOVEMBER)
Source: Own elaboration

In Figure 9, during November only 14.7% of the time the indoor ambient temperature is within the comfort zone, predominantly observed in the hours after noon, between 12:00 to 20:00. In the case of the temperature above the comfort zone, there was no higher temperature, so it is understood that mechanized cooling is not necessary during this month of November. In the case of temperatures below the comfort zone, more than 85.2% of the time were observed, which means that comfort can be achieved by shelter or even by the occupation of the space itself, given the anthropogenic heat.

This can be affirmed due to the fact that there are days with approximately 50% of the time within the comfort zone.

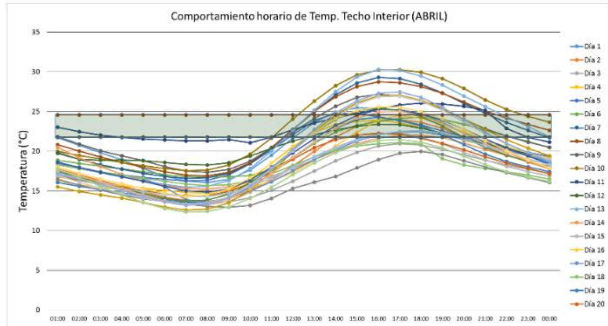

Figure 10 Comparative graph of simulation and hourly behavior, transitional period 1 in roof (April)
Source: own elaboration

Figure 10 shows the behavior of the interior surface temperature on the roof for the month of April, since using the insulating material only 16.8% of the time is within the comfort zone and 71.5% of the time temperatures are below the comfort zone. However, taking into consideration the approach to the warm period, temperatures below 21.8 C are manageable given the activity performed by the occupants inside the house and the heat emitted by household appliances and the heat produced by cooking food. The set of conditions together with the occupancy schedule, can combine to raise the indoor ambient temperature and approach or enter the comfort zone.

And in the case of the November period (transient 2), 13% of the time within the comfort zone also stands out during the afternoon hours, but 83% of the hours of the month the surface temperatures of the interior ceiling are below the comfort zone, marking the transient trend from warm to cold period (Figure 11).

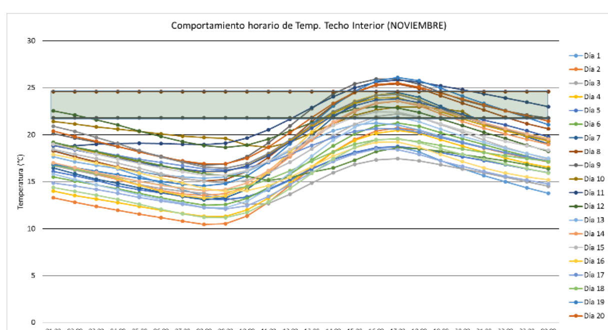

Figure 11 Comparative graph of simulation and hourly behavior, transient period 2 in roof (November)
Source: own elaboration

Conclusions of the analysis

In the comparison between the measured and simulated data, we could see that at any time of the year in periods that are not hot or cold in the warm dry climate in the Tijuana region, the comfort zone in the two periods are very similar, since having a unique phenomenon called santana winds makes the second transient period instead of being warm to be cold and that allows the indoor climate of the house to be very similar both in the March-April and November periods.

It should be noted that if the implementation of passive systems such as pergolas on doors and windows is done, in addition to the implementation of coatings such as one-inch polystyrene for thermal insulation, it is possible to mitigate the thermal gain of the house and reduce the variability of the indoor ambient temperature of the house in these periods, considering that the analysis that was performed does NOT contemplate mechanical devices for air conditioning, adaptation of the user to achieve optimal comfort. In this way, we managed to avoid excess (economic) expenses for families in the use of mechanical devices and their energy consumption, as well as health issues that could result from this practice. By using 1" of polystyrene it would only be a one-time expense and this benefits not only in the transitional period 1 and 2 but throughout the year by maintaining thermal stability within the space, i.e., a narrower range of temperature variation.

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Organic addition for mortar mixtures based on pitahaya cactus

Adición orgánica para mezclas de mortero basado en cactus de pitahaya

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Abstract

In the field of construction, and specifically regarding cement-based mixtures such as concrete, endless alternative materials have been implemented aiming at improving the physical, mechanical and chemical properties, reducing cement usage through the use of materials from an organic origin. In this sense, cacti species have gained ground in the construction industry, therefore, in this research work, the pitahaya species was studied. Pitahaya powder was characterized to replace cement in the mortar mix in percentages of 1% and 2%, evaluating the compressive strength at 28 days. Results showed that characteristics similar to those of nopal were obtained, such as the ability to store water within the pores, which leads to improvements in compressive strength with respect to the control mixture.

Cement-based mixtures, Cacti, Mortar, Organic additive, Concrete

Resumen

En el ramo de la construcción y específicamente en las mezclas base cemento como el concreto, se implementan un sinfín de materiales alternativos, con el propósito de mejorar las propiedades físicas, mecánicas y químicas disminuyendo el uso de cemento, mediante el uso de materiales de origen orgánicos. En este sentido, la especie de las cactáceas ha ganado terreno en el área de la construcción, por lo que, en este trabajo de investigación, la pitahaya se eligió como especie estudiada. Se caracterizó el polvo de pitahaya para sustituir el cemento en el mortero en porcentajes del 1% y 2%, evaluando su resistencia a la compresión a los 28 días. Los resultados muestran que se obtienen características similares al nopal, como la capacidad de almacenar agua dentro de sus poros, la cual que propicia mejoras en la resistencia a la compresión con respecto a la mezcla control.

Pitahaya, Mezclas Base Cemento, Aditivos Orgánicos

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Introduction

On a global scale, cement is one of the most widely used materials in the construction industry and will continue to be so unless there is a revolution in the materials industry. This is reflected in a high demand of it and, being the most used material in construction, it also becomes the biggest polluter due to its production process, which generates large amounts of greenhouse gases, since the manufacture of a ton of cement requires approximately 4 GJ (Giga Joules) of energy and the production of Portland cement clinker emits about a ton of carbon dioxide (CO_2) into the atmosphere [1,2]. Initially, it was thought that the cement mixture produced could withstand any climate or condition and it was assumed that this material did not require maintenance throughout its life span, which was relegated when durability problems arose in concrete structures, which deteriorate mainly in aggressive environments or due to the use of inappropriate materials as well as poor handling of construction processes, however, the greatest damage to structures is generally caused by the reinforcement steel corrosion and attack by chlorides [3,4].

This has evolved over the years, implementing new technologies to meet the demands of the concrete industry through the activation and development of special concretes in which mineral additions are used [5]. Most of the countries' infrastructure is built with this material, so it is very important to gain knowledge of the production process. Bad practices in construction result in deficiencies in concrete in terms of its properties, since once these problems arise, most of these structures cease to be functional, limiting their projected life span. From this perspective and taking into account that Mexico is a country with climatic diversity and aggressive environments, it is essential to know and control this issue [6,7]. In this sense, concretes are designed for different durability requirements; depending on the desirable properties, the components of the mixture, proportions and the way in which they interact with each other determine the concrete's useful life span [8]. Based on this, the use of organic materials as an addition in the concrete mixture, known mostly as organic additions, which are often available locally and are inexpensive, has improved the concrete's durability [9].

This is where Mexico plays an important role, since the use of these organic materials, such as cacti, of which there are more than 670 species, has gained ground in the area of construction and several authors [10] report that the most studied one is nopal, which presents favorable results in terms of physical, mechanical and durability properties when applied to mortar and concrete mixtures and compared to the implementation of some mineral additions made with materials such as fly ash and blast furnace slag, among others, or to additions of imported materials, which make their use more expensive and, although they improve their properties, they are not viable for large-scale application [11,12].

For this reason, cacti species, with a great diversity of species to study, have been widely implemented in the field of construction. Among the cacti are those of the genus *Hylocereus*, of which the most known species are *Selenicereus megalanthus*, or yellow pitahaya, and *Hylocereus undatus*, or red pitahaya [7,11]. Specifically, pitahaya is a plant that grows wild, whether on stones, living trees or walls. Pitahaya, like most cacti, is characteristically succulent, with many thorns and highly adapted to arid and semi-arid regions [13]. The pitahaya plant, and the parts that make it up, are used for different forms of purposes: ornamental, protective barriers, food and medicinal purposes, all of this can be made compatible with its productive function, which opens up a wide range of opportunities to implement its use in other areas. Therefore, the main objective of this work was to evaluate the effect of the addition of pitahaya cactus in a dehydrated form on the physical, chemical and mechanical properties (compressive strength) of a masonry mortar.

Experimental Section

Material procurement

The amount of material needed was estimated for the assessment of the physical and mechanical properties in the mortar mixture with the addition of pitahaya cactus in percentages of 1% and 2% and continue with the location of local suppliers to obtain the materials.

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Regarding the obtaining of the pitahaya, this was achieved through family crops suppliers, that is, they themselves produce the fruit, located in the Mayan region called “Los Chunes” route in the municipality of Felipe Carrillo Puerto, Quintana Roo, Mexico, Figure1.

Figure 1. Location map of the *Chunes* region

Physical characterization of fine aggregate

The materials were sampled according to the NMX-C-030 standard, which establishes "the sampling of the aggregates that are used in the investigation of potential sources of supplies”. The aggregate used corresponds to the bank called "El 21", according to the list of material warehouses in Quintana Roo, corresponding to the collection of warehouse No. 1, with coordinates 18°30'57.75” N - 88°29'04.79” W, being of the alluvial type of Qhoal category; this material contains weathered limestone, laterite clay and silt [14]. Equal portions of the aggregates from a mound (gravel or sand) were taken. Once the portions were obtained, they were mixed to obtain a representative sample of the total amount of material, as shown in Figure 2a. Subsequently, they were sampled according to the NMX-170 method, which explains the correct way of reducing the materials obtained in the field to the appropriate size for the test.

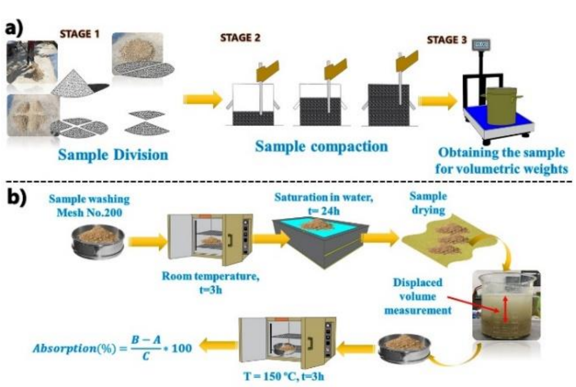

Figure 2 a) Process diagram for obtaining and reducing the sample and b) Scheme for the determination of density and absorption in fines

Volumetric weight of the aggregates

Dry Compacted Volumetric Weight (DCVW). 55 kg of fine aggregate were taken and, in accordance with NMX-030, they were reduced to a volume of approximately 1.5 times the capacity of the container. The container, with a volume of 5.05 liters, was filled up to one third of its volume and then the surface was flattened. The material was firmly mixed with a rod, applying 25 evenly distributed penetrations on the surface. Finally, the container was filled until the material exceeded the upper edge to obtain the final weight using Equation 1.

$$DCVW = \frac{W_m}{V_c} \quad (1)$$

Where, $\boldsymbol{W_m}$= Material weight /kg [$\boldsymbol{W_m}$ = $(W_{container} + W_{material}) - W_{container}$)], $\boldsymbol{V_c}$ = Container volume / m^3.

Dry Loose Volumetric Weight (DLVW). As for the DCVW test, the NMX-C-073 standard was used, which briefly consists of the "determination of the volumetric mass of fine and coarse aggregates or a combination of both". This method is applicable to aggregates whose maximum nominal size does not exceed 150 mm. The test procedure consisted of homogenizing the material by means of a correct mixing in dry conditions to continue with the filling of the container as shown in Figure 2a. Dropping the material from a height of 5 cm, trying to rearrange the material due to improper movements, scratching the excess. Subsequently, the container is weighed and the data is recorded, to finish with the calculation of the volumetric weight of the dry and loose material, through Equation 1.

Fine aggregate grading analysis and fineness modulus. The granulometric analysis was carried out in accordance with the provisions of NMX-C-077, using the sample obtained in the sampling of the aggregates, after its reduction. The granulometric limits of the fine aggregate were used according to the NMX-C-111 standard with respect to the size of the sieves, as indicated in Table 1

Sieve Number	% Passing the Sieve
9.5 mm (3/8")	100
4.75 mm (No. 4)	95 - 100
2.36 mm (No. 8)	80 - 100
1.18 mm (No. 16)	50 - 85
0.60 mm (No. 30)	25 - 60
0.30 mm (No. 50)	10 - 30
0.15 mm (No. 100)	2 - 10

Table 1 Fine aggregate grading limits

The fineness modulus (FM) of the fine aggregate was obtained in accordance with the NMX-C-111-ONNCCE standard, which was obtained by adding the accumulated percentages (by weight) of the aggregates retained in a specific series of sieves and dividing the sum by 100. On the other hand, to determine the density of the fine aggregate, the volume difference method was used (Equation 2); while, for absorption, the process described in NMX-C-165 was used.

$$D = \frac{MSSD}{DVD} \qquad (2)$$

Where, ***D*** = aggregate's density; ***SDSS***= surface dry saturated sample and ***DVD*** = displaced volume difference. For the obtention of the absorption percentage, Equation 3 was used with the data obtained from the process of saturation and drying of the fine aggregate:

$$\%Absorption = \frac{B-A}{C} * 100 \qquad (3)$$

Where, ***B***= dry sample weight, ***A***= saturated sample weight, ***C***= surface dry weight. The sample obtained was subjected to the washing process in accordance with the standard [1] to remove excess fines from the aggregate. The sample was divided into two equal portions of 1 kg and, subsequently, sieved through sieve number 200 to eliminate the fines within it, until the water did not present turbidity. Once the sample was washed, it was placed on the electric grill to dry, allowing it to cool to room temperature in a period of t=1h - 3h. Once the time had elapsed, the material to be saturated in water (700 ml) was placed for a period of t=24 h inside a covered metal container to prevent moisture loss. After 24 h, the fine aggregate density was determined by means of the water displacement method in conjunction with the NMX-C-165 standard, the process is summarized in Figure 2b.

Physicochemical characterization of Pitahaya

For a correct workability, a pre-grinding was carried out on the pitahaya stems, which allowed obtaining better results in the dehydration of the material. For this, a manual mill with an iron body and a capacity of 2 kg was used. Grinding was carried out until a smaller material was obtained. It is worth mentioning that this pre-grinding was done with fresh pitahaya stems, just as they are obtained from pruning. The dehydration process consisted of placing the collected and ground material in a muffle at a T_{max} = 175°C for t = 2 h to subsequently continue with the dehydration, which was carried out with a thermal process starting at room T until reaching T = 175 °C in a period of t = 3 h, as shown in Figure 3. Once the material was dehydrated, the sample was subjected to a mechanical grinding process, using a blender equipment with blades until obtaining a fine powder of 0.2 mm size.

Figure 3 Dehydration process

Thermogravimetric Analysis (TGA). The powder decomposition process during thermal heating was characterized by thermogravimetric analysis using a MOM – Budapest OD – 103 equipment in a temperature range of T= 0°C to 800°C with a heating rate of 10°C/ min.

Determination of the chemical composition, through X-Ray Fluorescence analysis (XRF). XRF data were obtained with a Philips PW – 1050 X´ diffractometer using radiation of Cu Kα = 1.5487 Å. The diffraction patterns were run over a range of 2θ = 10 – 100° with a step of 0.02 in 2θº.

Determination of the morphology, through an analysis of Scanning Electron Microscopy and Dispersive Energy Spectroscopy (SEM-EDS).

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The morphology and microstructure of the materials were performed using a SEM (JEOL, model JSM-6510LV) equipped with an energy dispersion spectrometer (EDS, BrukerXFlash 6I10).

Mix Design and mechanical characterization

The mix design was determined with respect to the number of variables available, which are shown in Table 3. Where, Vc is the volume of cement, Vsd the volume of sand and Vw the volume of water. Three types of mixture were made, the first one was the control mixture (MC_0), another mixture with 1% addition of pitahaya cactus (MP_1) and the third one with 2% addition of pitahaya cactus (MP_2). The volumes' method was used with the data shown in Table 3.por paso, que se estimó mediante calculo y mediante las pruebas de flujo en secciones posteriores.

	CONTROL MIX			
	% Fluidity	110.0%	**Ratio a/c**	0.54
Real Volume	0.00050	**m^3**		
Vc	0.331	**kg**	331.5	**gr**
Vsd	0.655	**kg**	687.75	**gr**
Vw	0.179	**lts**	178.9	**ml**
	MIX WITH 1% ADDITION			
	% Fluidity	112.3%	**Ratio a/c**	0.57
Real Volume	0.00050	**m^3**		
Vc		344.58		**gr**
Vsd		687.75		**gr**
Vw		200.01		**ml**
	MEZCLA CON ADICION 2%			
	% Fluidity	113.5%	**Ratio a/c**	0.59
Real Volume	0.00050	**m^3**		
Vc		344.58		**gr**
Vsd		687.75		**gr**
Vw		206.07		**ml**

Table 3 Mix design

Fluidity in Mortar. This test was carried out in accordance with NMX-C-486 to obtain a workable concrete mix; briefly, for a mix to be considered workable, it must be within the limits of 110 ± 5% for CPC 30R cement, starting with a percentage of water calculated in the mix design and varying its volume. For each one of the volumes, the diameters were measured, and the fluidity was calculated with Equation 4. This procedure was repeated for the mixtures with 1% and 2% addition of dehydrated pitahaya, until the necessary fluidity was found.

$$\% \, Fluidity = \frac{(Average\ diameter - Initial\ diameter)}{Initial\ diameter} * 100 \qquad (4)$$

Compressive Strength. Cubes with dimensions of 5 cm x 5 cm were made, which were pre-conditioned and cleaned, avoiding previous residues. The elaborated specimens, after 28 days of curing, were tested to determine their compressive strength. These specimens, once taken to failure in the aforementioned test, were crushed and the obtained powder was characterized by SEM to know its morphology.

Results and Discussion

Physical characterization of fine aggregate

Regarding the characterization, this turned out to be within the lower (LL) and upper (UL) limits established in accordance with the NMX-C11 standard, as it can be seen in Figure 4. From this, an FM of 2.83 was obtained.

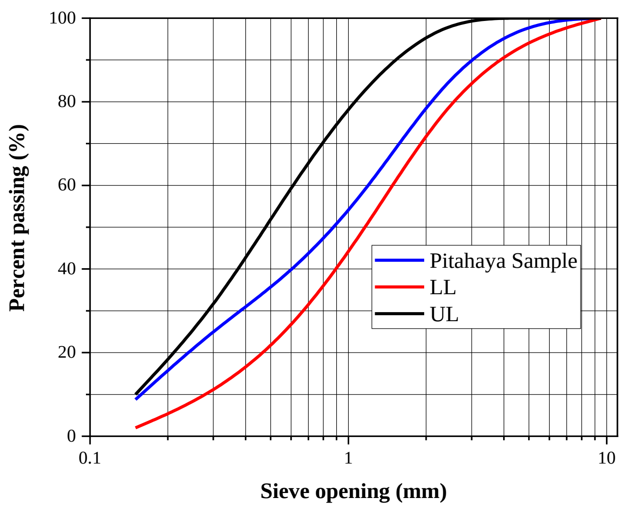

Figure 4 Fine aggregate grading graphic

Similarly, results of the characterization, described in Table 4, show a high percentage of absorption, which is why, according to the literature, they are classified as high absorption aggregates [14]. Due to this, the mix design required a higher percentage of water, since, being a material with high absorption, it will need more of it, so that, otherwise, in the hydration process, the water consumed will leave spaces, causing pores and fissures and consequently, the quality of the mix will be affected [17].

Aggregate	DLVW (kg/m^3)	DCVW (kg/m^3)	Absorption (%)	Relative Density	Wear (%)	Fineness Modulus
Fine aggregate	1.31	1.76	5.26	2.86		2.83

Table 4 Fine aggregate characterization

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TGA Analysis. TGA analysis allowed to determine the thermal conditions at which the pitahaya powder begins to decompose. The TGA curve showed a behavior of mass loss with the increase in temperature, as shown in Figure 5. The TGA graph showed a rapid weight loss in a range of 25°C - 126°C (I) of at least 7% of the initial weight, associated to water loss [3]. A second weight loss of about 10.96% in a range of 126 °C – 177 °C (II). A third more pronounced loss of 75.08%, in a range of 177 °C -323 °C (III), which is related to the decomposition of polysaccharides [18,19], stage that does not produce the best properties in the pitahaya powder for its implementation in the mortar mix. These components help to improve the properties in the mixtures, so, according to the results and the literature, the optimal range would be between T=126°C – 177°C (II) [20]. In sections III and IV, the loss of elements corresponds to the polysaccharides [3].

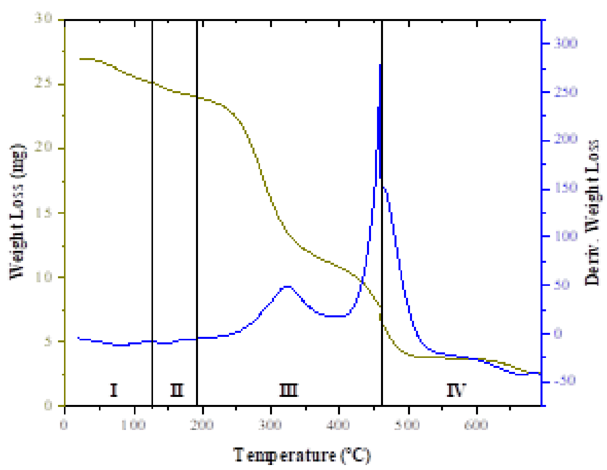

Figure 5 TGA curve for pitahaya powder

XRF Analysis. To identify the presence of elements that favor the implementation of the powder in the mixture, an XRF analysis was performed. Results, shown in Figure 6, exhibit the presence of calcium in a higher concentration percentage of 70.15%, Manganese (Mn) of 0.61%, Iron (Fe) of 1.96%, which is characteristic of this type of species such as nopal [4,8,12,20]. This element (Ca), which is found as Calcium Oxide (CaO), together with those of the cement, can accelerate the hydration process in the mixtures, due to the higher percentage of calcium, which is present in the main phase (Alite) responsible for the initiation of setting and early strength [21].

The pitahaya powder presented mostly Ca elements, so, as mentioned in previous lines, it can be beneficial for the initial phase of hydration and resistance [2].

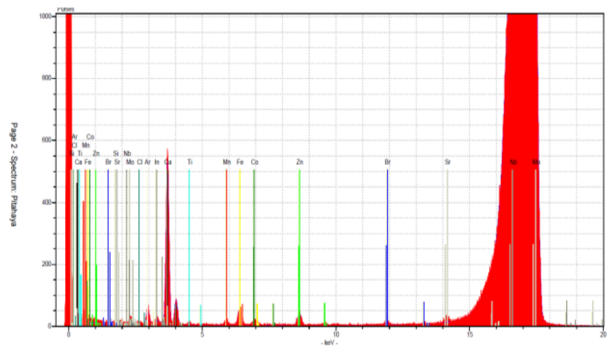

Figure 6 XRF analysis of the pitahaya powder

SEM-EDS. Results of the SEM analysis for the pitahaya powder are shown in Figure 7, where a polygonal structure can be observed due to particle size as reported in [22][22]. It is also possible to observe the surface of the particles, which tends to have a rough shape [23]. Some reports also indicate that this kind of structure can be associated with the drying conditions and the extraction method [24]. The EDS analysis shows the presence of elements such as Carbon (C), Oxygen (O) and Calcium (Ca), belonging to this type of species such as nopal [25]. As for these elements found, they tend to the molecular structures of sugars where these elements predominate [26]. As shown in Figure 8a, these elements correspond to the formation of some crystals corresponding to calcium oxalates, which is the most common in this type of material [27]. When these components come into contact with water and cement, they react favorably, improving in the curing stages, causing these particles to store large amounts of water, covering the network of interconnected pores and acting as an additive for a good hydration of the mixture [20].

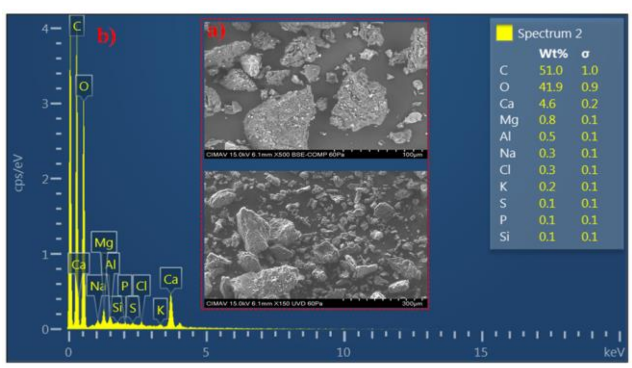

Figure 7 a) SEM images at 500x and 150; b) ESD of dehydrated pitahaya powder

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Fluidity in mortar

Once the volumes of cement, water and sand were obtained, the fluidity test was carried out to determine the correct volume of water. The data obtained is shown in Table 3. It is possible to observe that the correct amount of water to comply with the standard was 155 ml, with which the w/c ratio was modified. Subsequently, two tests were carried out with an established volume of water, the first one with a volume of 150 ml, in which the lack of workability was noticed because of the high density of the mixture, which reached a fluidity of 85.55% and the second one with a volume of 155 ml, where the fluidity was optimal with 110%, as it can be seen in Table 3.

Implementing the same procedure of the NMX-C-486, the volume of water was increased from 150 ml to 155 ml for the control samples, in this case, the mixture showed greater workability when it was emptied into the cone. At the end of the process, the diameters were measured to verify that the mixture complied with the appropriate percentage. The mixture with 155 ml of water was adequate to meet the standard. In the case of the mixtures with addition of pitahaya powder of 1%, the mixture was made with the parameters established in the NMX-C-061 standard, which complied with the percentage of fluidity in the control mixture. The mixing process was similar to that of the control sample with the difference that, at the time of pouring the cement, the pitahaya powder was added too. For this test, the volume of water needed to add to the mortar mix for the cubes was obtained. After having carried out the same procedure for the mixtures with the addition of 2%, no inconvenience was noted at the time of the mixing process. Similarly, the volume of water (Table 3) for the mixtures with 1% pitahaya powder was obtained by increasing 5 ml of water. For the volume of 165 ml, the mixture did not meet the standard, so the volume was increased by 5 ml. The optimal volume of water for the mixture with the 2% addition was 170 ml, which complied with the percentage established in the standard.

At the end of each of the mixtures, it was observed that the samples with the addition of pitahaya needed a greater amount of water to obtain the appropriate fluidity percentage, since these materials tend to store water inside their pores. Table 3 shows that, as the addition percentage of pitahaya powder increases, and the percentage of cement decreases, the w/c ratio increases. These results were similar to those described in several research works where they have implemented cacti such as nopal and dehydrated aloe and the authors agree with the increase in the volume of water in the mixtures, due to the type of organic material which has properties of storing water in the pores [20].

Preparation of specimens

After obtaining the parameters for the adequate workability of the mixtures, the mortar cubes were made, as shown in Figure 8, according to NMX-C-061. Obtaining a total of 3 mixtures (0%, 1% and 2%), with 4 samples each, at the age of 28 days. During the elaboration process, no change in the color of the mixture was noted, which could be related to the low percentage of addition; in contrast, a characteristic odor was perceived at the time of mixing due to the addition of pitahaya powder.

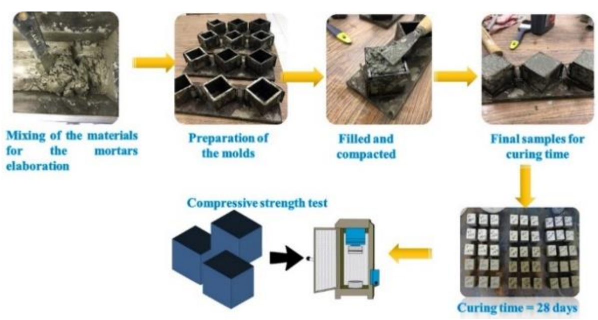

Figure 8 Elaboration process of the mortar mixtures for the different addition percentages

Mechanical and structural Characterization of mortars

Compressive strength. Figure 9a shows the results of the compression test evaluated at 28 days, in which it is possible to appreciate that this mechanical property improved significantly; in the case of the sample with 2% addition, it presented a decrease in resistance with respect to that of 1% addition, this is due to the higher percentage of pitahaya powder, since this material, as mentioned above, has the ability to store water within its structure [20].

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So that those spaces left by the water particles within the matrix were not occupied by the cement particles [7,28]. Another behavior that is noted in Figure 10b is that the increase in resistance values improves as the percentage of fluidity increases, making these mixtures more workable. These results agree with what was found in other investigations, where the addition of a cactus species improved this property in percentages lower than 2% [29].

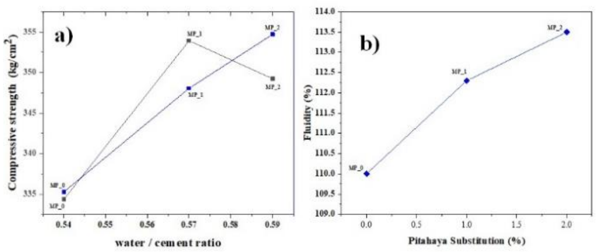

Figure 9 a) Compressive strength of mortar cubes and b) relationship between fluidity and percentage of pitahaya powder

It is important to mention that, in research works where nopal powder was implemented, the optimum amount was less than 1% since, when that amount is exceeded, the compressive strength decreases, due to the fact that the material absorbs more water and, in the hydration, process generates voids that affect the quality of the mixture [11]. For the case of the addition of dehydrated pitahaya, the proportions of 1% and 2% significantly exceeded the resistance of the control sample, even though they presented an increase in the w/c ratio.

SEM analysis in mortar mixtures. SEM images taken from the mortar cubes were analyzed, which were crushed in order to extract the powder from it.

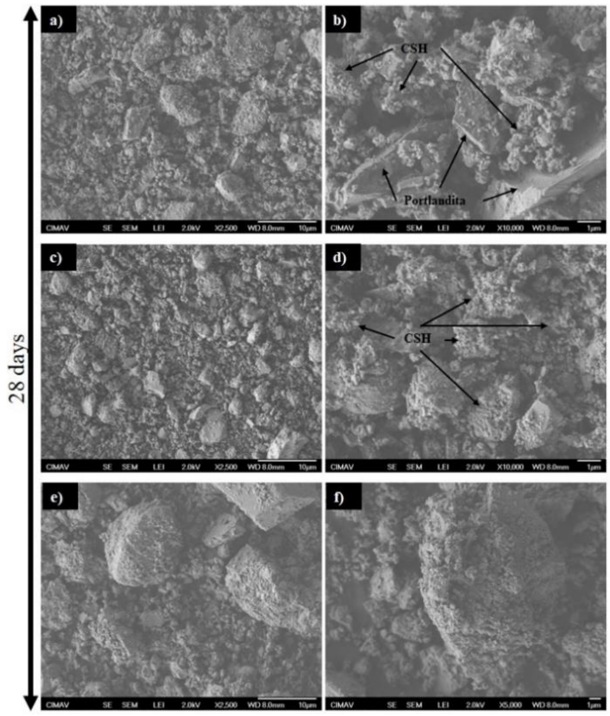

Figure 10 SEM micrograph of 0% (a and b), 1% (c and d) and 2% (e and f) at 28 days of curing

Figure 10a and b show images of the control mixture (0%) and the presence of portlandite crystals and calcium silicate hydrate (CSH), product of the hydration of the mixture [5]. For the sample with 1% addition of pitahaya powder, Figure 10d shows more hydration products due to the implementation of pitahaya powder and, as a result, the increase in compressive strength [4]. In the case of the mixture with 2% addition, it was possible to see small sponges that were not found in the control mixture, which may be particles of pitahaya powder and, like PM_1, it is possible to see hydration products. as CSH around said particles. These elements favor the hydration of the mixture, making it less permeable.

Conclusion

It was possible to observe that, during the characterization of the pitahaya powder, it has elements such as Carbon (C), Oxygen (O) and Calcium (Ca), which make it compatible for the implementation of this material in mortar mixtures. Likewise, the presence of portlandite crystals and hydrated calcium silicate (CSH) was noted, product of the hydration of the mixture in the additions of 1% and 2%. In the characterization, the optimum decomposition range of the material was also obtained, showing values similar to those obtained for nopal.

For the particular case of pitahaya, values between T=126 °C – 177 °C would be appropriate according to the dehydration method implemented in this research work. The implementation of this material, like its close relative the nopal, showed water storage capacity, a peculiar property of this species and a fundamental part for the improvement of the characteristics of the mortar mixtures. This property was reflected in the compressive strength, since the addition of pitahaya powder improved the strength values for MP_1 (353.93 kg/cm^2) and MP_2 (349.24 kg/cm^2), with respect to the control sample (MP_0) of 334.5 kg/cm^2, achieving in the same way the reduction of cement. It was noted that this increase in resistance is related to the percentage of substitution even when the percentages of fluidity increased, acting as an ecological alternative for this type of mixture. The values of these mixtures exceeded the control mixture in percentages of 5.80% for PM_1 and 3.93% for PM_2 due to the development of hydration products and a more compact morphology that possibly reduced permeability due to the implementation of pitahaya powder and, as a result of this, the compressive strength increased by 5-10% on average for the 1% and 2% additions. The use of cacti in cement-based mixtures is still under study, so this research work has only focused on the Hylocereus undatus species, however, it is necessary to expand the research on applications for the construction industry.

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Implementation of a home automation system to automate the functions of a community centre due to the sanitary measures implemented by the COVID-19 pandemic

Implementación de un sistema domótico para automatizar las funciones de un centro comunitario debido a las medidas sanitarias implementadas por la pandemia del COVID-19

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Abstract

Current technology has led to solutions that seem taken from science fiction, cars with semi-automatic pilots, traffic lights with sensors to control traffic jams and one of the most important and the main focus of this article, the automation of buildings and homes for the management and monitoring of general services. This automation is called home automation and it offers many facilities to manage buildings remotely or automatically, which currently helps a lot with the global pandemic of COVID-19. This project is aimed at the implementation of a home automation system in a community center in Tres Ríos, La Unión, Cartago, which would facilitate and help restore the normal operation of said center. The system will turn the lights on and off, control the temperature, measure distance and verify gas or smoke leaks in order to facilitate management and help maintain the sanitary protocols required by law for the normal operation of the center.

Computing, Home automation, Arduino, Automation, COVID-19

Resumen

La tecnología actual ha permitido llegar a soluciones que parecen sacadas de la ciencia ficción, automóviles con pilotos semiautomáticos, semáforos con sensores para controlar los atascos y uno de los más importantes y el foco principal de este artículo, la automatización de edificios y viviendas para la gestión y monitorización de los servicios generales. Esta automatización se denomina domótica y la misma ofrece muchas facilidades para gestionar edificios de forma remota o automática, lo cual puede ayudar mucho en diversos casos como por ejemplo en la pandemia mundial de COVID-19. Este proyecto se orienta a la implementación de un sistema domótico en un centro comunitario en Tres Ríos, La Unión, Cartago, Costa Rica, con el fin de facilitar y ayudar a restablecer el funcionamiento normal de dicho centro. El sistema encenderá y apagará las luces, controlará la temperatura, medirá distanciamiento y verificará fugas de gas o humo para de esa forma facilitar la gestión y ayudar a mantener los protocolos sanitarios exigidos por la ley para el funcionamiento normal del centro.

Computación, Domótica, Arduino, Automatización, COVID-19

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Introduction

The technological revolution that the world has been experiencing over the last 50 years has impacted every facet of human beings' daily lives, according to Schwab (2016) in his book The Fourth Industrial Revolution. After the marked development of electronics, starting in the 1960s, as well as the development of new technologies oriented towards communications and applied to life, a change has been generated in the majority of people living in a globalised environment, where connectivity plays a predominant role and even the simplest element such as a mobile device functions as a mechanism of transition to the dynamics of global interconnectivity.

Because of this, in recent years society has been undergoing one of its greatest economic and social revolutions, which focuses on information and connectivity as elements of development; sociologist Alvin Toffler (1979) calls it the Third Wave, other authors call it the communications age or the information revolution and it is proving to be a complex phenomenon in constant evolution. These changes introduce a technification of society and, in particular, the use of computers to transmit and process data.

The transformation of traditional homes into smart homes, through the incorporation of certain tools, transcends the limits of comfort towards efficiency and environmental sustainability. The aforementioned is known as home automation and according to Sánchez (2017) it is understood as the automation of as many systems as can be found in a home, relating them to each other, with specific technological products for this purpose. Now, it is important to mention that the automation of environments was considered for many years a technological vanity within the reach of the most privileged groups of society, but nowadays its massive use is the reason for multiple investigations such as the use of robots that clean the house, attend to sick people or simply automatically notify the authorities when there is an emergency in the home.

The applicability of this project is aimed at the automation of a community centre in processes such as: temperature control, smoke control and social distancing control; this in order to help control the health measures implemented due to the COVID-19 pandemic. It seeks to limit human involvement in the management of the venue in order to provide a safer environment for attendees. This research also represents a significant advance in terms of the appropriation of new technologies from a current perspective, opening the possibility of strengthening the local home automation industry.

Theoretical development

The 20th century was characterised by a great advance in all the fields where the human being has developed, this era has been described in many different ways: atomic era, television era, computer era, space era, computer era. This shows that the human race has come a long way in just a few years, and there is no doubt that informatics and computing have played a major role in this development.

Also, in recent years, driven by computing, other branches have emerged that are gaining momentum and have enabled human beings to carry out unimaginable activities. One of these branches is electronics, through which human beings use machines to carry out productive processes, playing a very important role in companies, as it helps to achieve maximum efficiency in the operations carried out (Villar Bonet, 2017). The revolution achieved by electronics has not only reached large industries that manufacture products on a large scale, but there is now a machine for almost every kind of work, in medicine, education, meteorology, industrial design, etc., and all this based on a component that was introduced in 1964 in the IBM system 360 computer called an integrated circuit (Long, 1999).

These circuits are a board composed of certain semiconductor materials (Espino, 2019), which function depending on the flow of electrons they obtain for the generation, transmission, reception or storage of information, among other functions.

Such circuitry is found in absolutely all modern technology and can be capable of receiving a wide variety of types of information, such as voice or music on a radio receiver, or an image on a television screen, or numbers on a computer.

This whole process of electronic transformation begins with the first generation of computers, which is marked by the use of vacuum tubes, a device consisting of a glass tube with electrical components that is sealed in a vacuum. The first computer to use this type of component was the ENIAC, which carried out its storage, calculation and control operations by means of electronic circuits (Long, 1999).

Vacuum tubes made it possible to amplify radio signals and weak sounds, and to superimpose sound signals on radio waves.

Due to the breakthrough in the use of tubes at the time, they were specialised for different functions and this made possible the rapid advancement of computer technology before and after World War II.

In the years following World War II, progress in semiconductor technology is attributed in part to the intensity of research associated with the space exploration initiative, which led to the development of the first integrated circuit in the 1970s.

These simple, yet complex, electronic circuits are what are found today in devices such as microcomputers, microwaves, sound and video equipment, and communications satellites.

With the origin of integrated circuits and their main functions clear, we can move on to explain the heart of the project that was developed, i.e., the Arduino.

Figure 1 Arduino UNO R3
Source: https://www.amazon.com/

The Arduino, as shown in Figure 1, is one of the most popular boards in the world when it comes to creating electronic circuits. Another quite similar board on the market is the Raspberry Pi, but the Arduino differs in that it offers an open hardware foundation for other manufacturers to create their own boards.

In general terms, the Arduino is an open source electronics creation platform and is based on free hardware and software, flexible and easy to use mostly by creators and developers (Torrente, O., 2013).

This platform makes it possible to create different types of circuits from a single board with which different applications can be developed according to the use that is needed. As mentioned above, Arduino is a free platform, since at the hardware level it is considered as a device whose specifications or diagrams are publicly available, so anyone can replicate them. This means that Arduino openly offers the basis for any other person or company to create their own boards, being different from each other, but being created from the same base.

Free software refers to computer programmes whose code is accessible to anyone who wants it, and can be used and modified without any problem with the original author (Zamora, 2016).

Likewise, the Arduino has the Arduino IDE platform, which is a programming environment that makes it possible for anyone who wants to create applications for Arduino boards, so that they can be given all kinds of utilities.

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Methodology

In order to build the home automation system in the community centre in the town of Tres Ríos, which is used by people of all ages in the community, the following electronic elements were needed and were used as primary inputs or instruments in the construction of the main circuit:

- 1 Arduino UNO board.
- 1 small protoboard.
- 1 temperature sensor TMP36.
- 2 servomotors.
- 1 ambient light sensor (phototransistor).
- 1 10kΩ resistor.
- 2 light bulbs.
- 1 ultrasonic distance sensor (HC-SR04).
- 1 Wisen gas sensor.
- 1 100kΩ resistor.
- 2 buzzers for the alarms.

Because the system was made virtually, we also made use of the AUTODESK Tinkercad web software for the simulation of the programme, this is a free software that allows us to work and make controlled simulations with the Arduino UNO R3 board.

It should be noted that because the board is not capable of performing multiprocesses, each sensor was programmed one after another, and what is done to simulate a multiprocess, is to avoid long times to congest the program, and avoid redundant programming so that, in case of a change detected in any of the sensors, it acts quickly with its due process. Figure 2 shows the complete circuit assembled in the AUTODESK Tinkercad software.

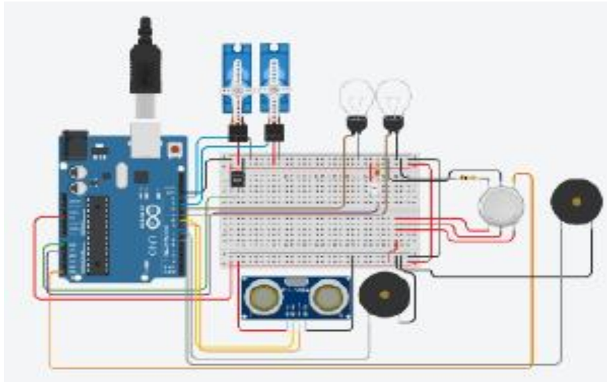

Figure 2 Developed circuit
Source: own elaboration

The following is a detailed description of how the system was assembled:

To begin with, the temperature sensor was connected to the Arduino board and programmed so that when the temperature is higher than 25 degrees Celsius, it opens the windows and turns on the ventilation (the servomotors perform the simulation of these) and when the temperature returns to be less than 25 degrees Celsius, the windows are closed and the ventilation is turned off to maintain the temperature. The Arduino board, through the analogue pin A0, reads the voltage received by the TMP36 sensor and by means of a mathematical operation, calculates the temperature and displays it on the serial monitor. The TMP36 sensor is an analogue input component, that is to say, its operation consists of delivering the information corresponding to the temperature of the environment by means of the voltage on its signal pin, the Arduino board in turn receives the signal and reads it with one of its analogue input pins. It should also be remembered that servo motors are part of a closed-loop system and are made up of several parts, namely a control circuit, servo motor, shaft, potentiometer, drive gears, amplifier and an encoder or resolver. A servomotor is a self-contained electrical device that rotates parts of a machine with high efficiency and high precision.

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For the illumination sensor, it sends the reading to the A1 analogue pin and when the sensor receives some illumination, the light bulbs are switched off, to reduce the light consumption as it is daylight or there is some external illumination. If the amount of illumination received is reduced, the Arduino board turns the bulbs on. In this case a simple phototransistor was used, which detects ambient light. It is the opposite of an LED: when light hits the interior, it causes current to flow from the long pin to the short pin. This sensor has a built-in optical filter so it will do a good job of detecting light levels just as the human eye does.

For the distance sensor, what was done was to use the HC-SR04 sensor which sends a pulse through the trigger, and by means of a mathematical operation, plus the time it takes to receive it, the distance it is measuring is calculated; now, if the distance is less than 180 centimetres, an alarm will sound through the buzzer, indicating that the social distance is below the required distance due to the measures against COVID-19. It should be remembered that a buzzer is a device that converts electrical energy into sound, producing a sound of a specific tone depending on its use, generally used for alerts or warnings.

Finally, a gas sensor was installed, which is responsible for alerting in the event of a leak, whether it is gas or smoke. This, likewise, sends a signal to the board via an analogue pin, and if the board detects that the signal is above it triggers the alarm, and sends a warning through the serial monitor. Gas sensors are devices that indicate the presence of a specific gas, in some cases they can be configured or, in case of more accurate sensors, they measure the gas concentration. Gas sensors are used to prevent exposure to combustible and toxic gases.

Results

The results obtained with the four sensors used within the system reflected optimal performance within the system and this was of great benefit to the performance of the entire circuit.

The first results that were observed were obtained with the temperature sensor, as the servomotors (ventilation simulation) were properly activated according to the temperature range needed as shown in figure No.3.

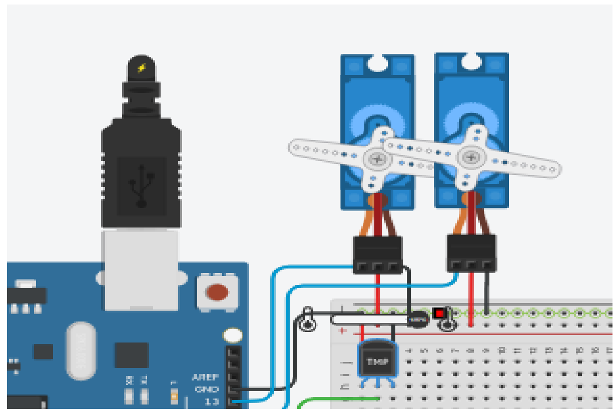

Figure 3 Use of servomotors and temperature sensor
Source: Own elaboration

With regard to the lighting sensor, its function of receiving the lighting and sending a signal to the analogue pin so that the Arduino performs the logical operation of activating or deactivating the lights was totally successful and ensured that this functionality of the system performed well, as shown in figure 4.

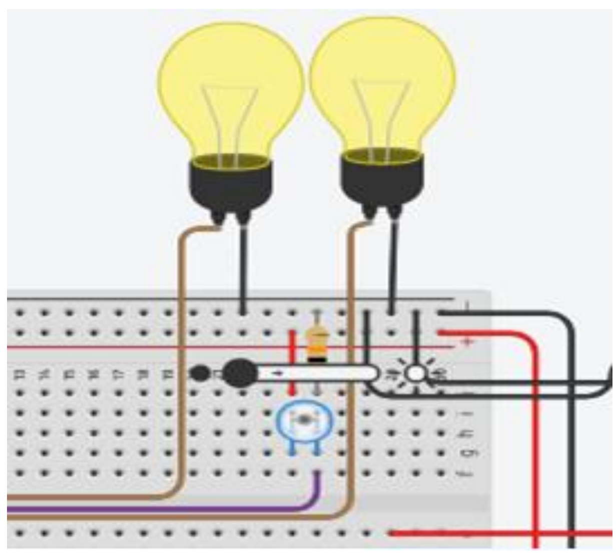

Figure 4 Lighting sensor
Source: Own elaboration

Consequently, the HC-SR04 sensor is the most widely used sensor of its type due to its versatility. It is a low-cost distance sensor that uses ultrasound to determine the distance of an object in a range of 2 to 450 cm.

And in this case it had an acceptable and accurate performance when measuring the distance required by the social distance, i.e. 180 cm, to then trigger the alarm or buzzer that gives the indication to people about the disrespect of the allowed distance. It should be noted that the buzzer has a very high-pitched sound that can be annoying, so it should be investigated how to improve the sound of the buzzer. Figure 5 shows how the sensor worked and the buzzer was activated at a distance of 198 centimetres.

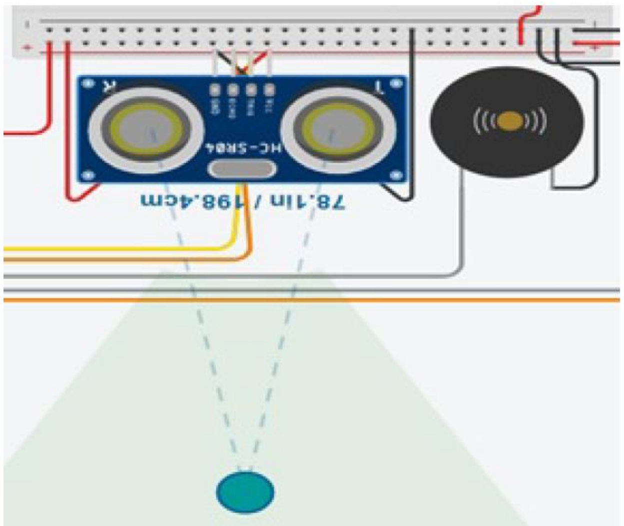

Figure 5 Use of the distance sensor
Source: Own elaboration

Next, the system used a gas sensor whose function is to detect if there are gas leaks, or if there is a high presence of smoke and thus send an alert if the presence is slight, and if there is a high presence, activate an alarm or buzzer to alert and make the people present in the community centre evacuate immediately. As with the other sensors, the performance of this sensor was adequate and caused the buzzer to sound at the slightest detection of smoke as shown in figure 6.

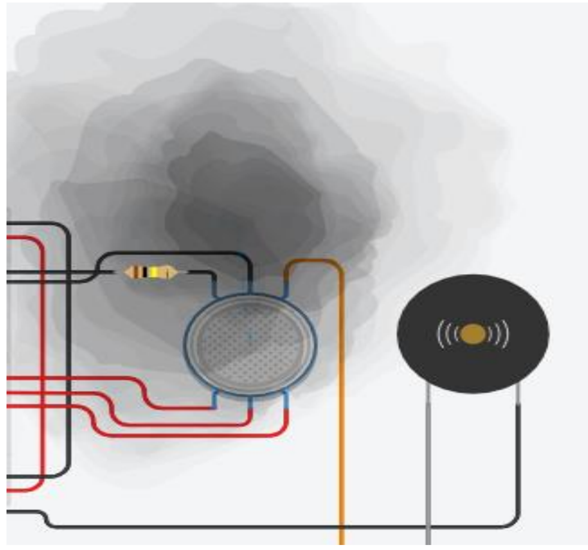

Figure 6 Use of gas sensor
Source: Own elaboration

Consequently, quite a few lines of code were used in this system, as it had to control electronics elements that not only have programming, but also mathematical formulas for precise calculations. All the code was written in the C++ language, which is very similar and contains many of the same functionalities as the Java programming language. In general terms, it can be said that all the proposed objectives were met, as the whole system worked satisfactorily.

Likewise, once the circuit was assembled and tested in the simulator, a demonstration was given to the staff of the community centre and some potential users. At the beginning, the use of the domotic circuit represented a challenge for the employees and assistants of the centre, since they were not used to the handling and interaction with a similar system, there were moments in which the employees did not know how to handle the sensors or the users did not understand the reason for the alarms, but once the functioning of the circuit was explained to them, positive comments and feedback were received from them, indicating that thanks to this type of initiative they feel more confident to attend work or the activities that are carried out. This represents an important step towards the implementation of home automation systems in other government buildings, as it demonstrates their effectiveness.

The use of this type of domotic circuit in a community centre can bring advantages to the different administrative areas of this, since due to the use of sensors such as ambient light and temperature, a reduction in the payment of the electricity service is generated, actions such as: dimming lights, regulating the temperature or activating air conditioners automatically also avoid the waste of resources of the community centre. The gas and ultrasonic sensors were able to take preventive measures against possible fires and crowds, which makes the administration of the community centre, in an economical and simple way, facilitates the creation of a safe environment for attendees and workers.

Finally, another positive change brought about by the implementation of the proposed domotics system is to be able to resume the activities that could not be carried out due to the COVID-19 pandemic, and this obviously generates the return of clients and, consequently, an increase in economic income. This improvement that can be achieved thanks to the efficiency of the system makes it possible to achieve the corresponding health measures, in addition to the fact that many people are more interested in attending the activities carried out by this community centre because they feel safe.

Conclusions

The administrators of the community centre can continue with other tasks while the Arduino-based home automation system is in charge of controlling the different sensors so that the cultural centre continues to function in the best possible way.

Thanks to the automation that can be achieved through the home automation system, a great improvement in the performance and administration of the community centre can be achieved. It is important to keep in mind that the use of this technology is of great help to work in a better way in any place, or in case you want to implement a system that helps to perform different tasks at home in a simpler way, since its use is growing dramatically.

It is also important to take into account the use of this type of sensors with Arduino to control the health measures implemented by the government due to the pandemic of COVID-19, is something very new that not only assists in the administration of the community centre, but provides a safe environment for those interested in attending activities and is also quite useful to prevent accumulations of people. If more of these systems were implemented in different venues that have a large number of customers, it would prevent contagions, save more lives and make people feel safer when entering these venues, so it is important to continue to encourage the creation of such systems.

Acknowledgements

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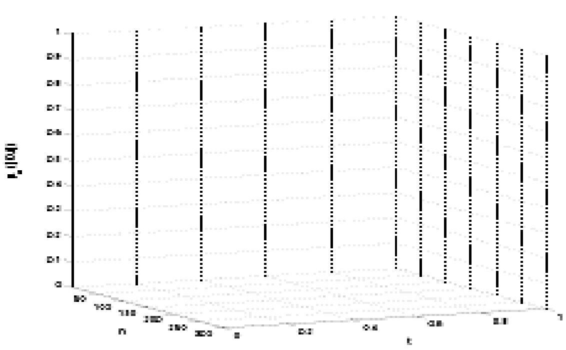

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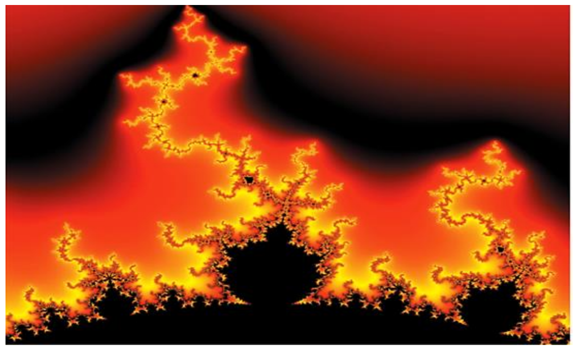

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