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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.

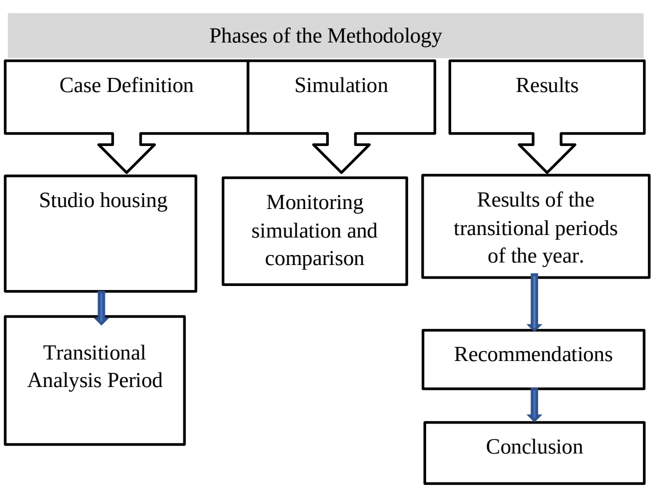

Table 1 Methodology
Source: Own elaboration

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.

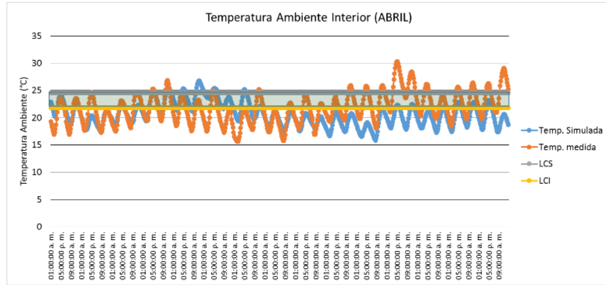

Figure 3 Comparative graph of simulation and monitoring in transitional period 1, April
Source: own elaboration

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).

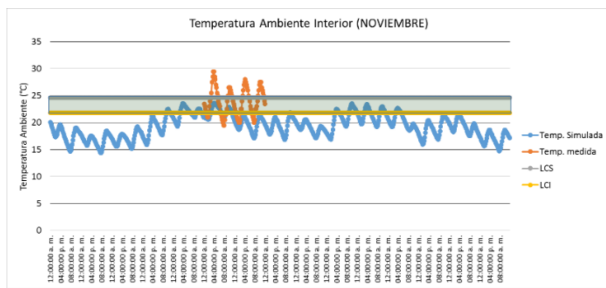

Figure 4 Comparative graph of simulation and monitoring in transitional period 2, November
Source: own elaboration

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.

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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.

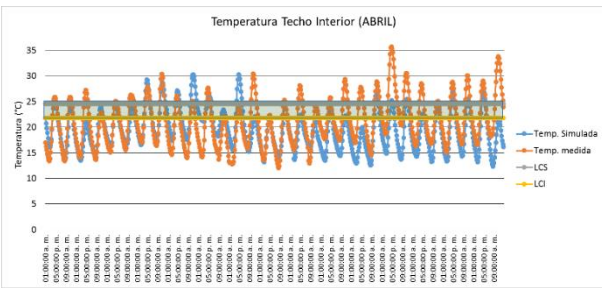

Figure 5 Comparative graph of simulation and monitoring in transitional period 1 in roof
Source: Own elaboration

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.

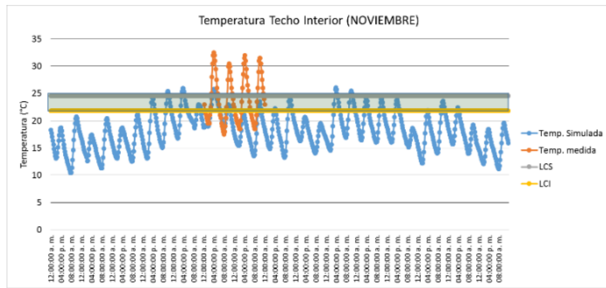

Figure 6 Comparative graph of simulation and monitoring in transitional period 2 in roof
Source: own elaboration

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).

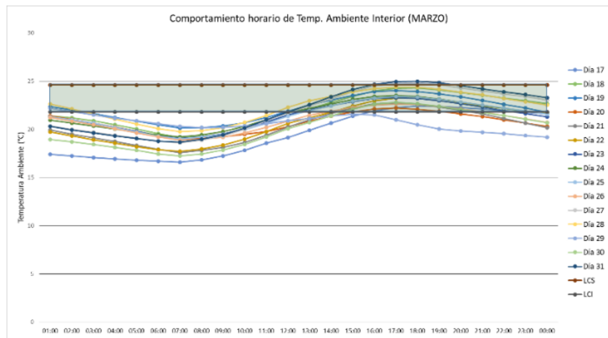

Figure 7 Comparative graph of simulation and hourly behavior, transient period 1 in indoor environment (March)
Source: own elaboration

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.

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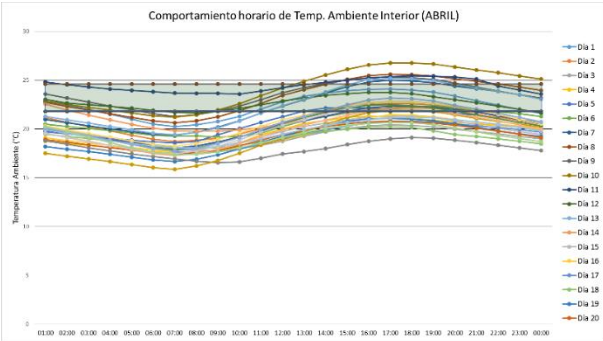

Figure 8 Comparative graph of simulation and hourly behavior, transient period 1 in indoor environment (April)
Source: Own elaboration

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).

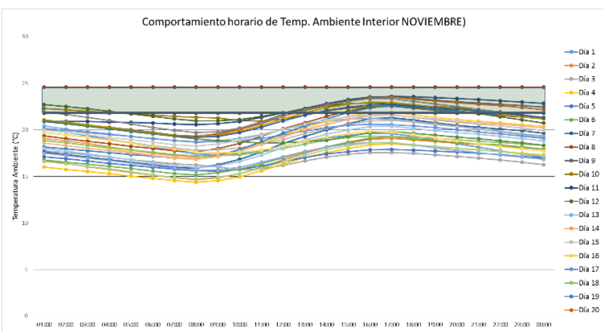

Figure 9 Comparative graph of simulation and hourly behavior, transient period 1 in indoor environment (NOVEMBER)
Source: Own elaboration

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.

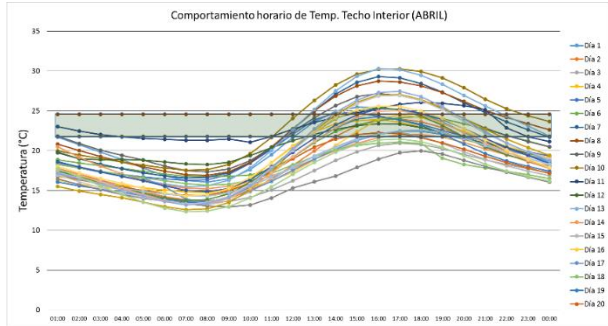

Figure 10 Comparative graph of simulation and hourly behavior, transitional period 1 in roof (April)
Source: own elaboration

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).

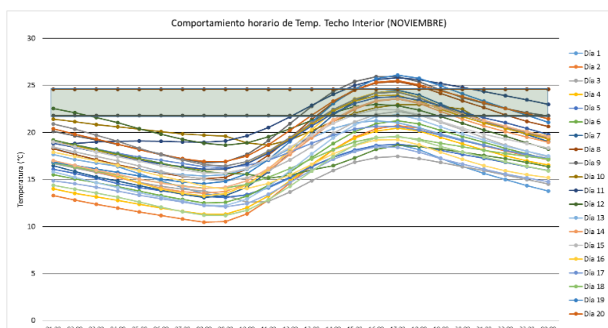

Figure 11 Comparative graph of simulation and hourly behavior, transient period 2 in roof (November)
Source: own elaboration

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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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