SIMULATION OF THE THERMAL PERFORMANCE OF LOW COST HOUSES IN VENEZUELA TO IMPROVE THERMAL COMFORT

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ABSTRACT

This work aims to investigate the thermal behaviour of low cost houses widespread in many regions in Venezuela and discuss their suitability to climatic conditions, aided by ArchiPak™, a simulation software developed by Dr. Steven Szokolay. The simulation conditions correspond to three important cities located at different altitudes: Caracas (880 m), Maracaibo (40 m) and Mérida (1500 m). Frequently the occupants complain of low thermal comfort, especially in the warm-humid climate which prevails in most of the cities and populated areas. As a solution the owners undergo some modifications based on installing air conditioning equipment which is accompanied with additional energy consumption and maintenance costs. The results showed that the inside temperature at low altitudes is very high and houses are uncomfortable the whole year. At mid and high altitude the temperatures are close to the comfort zones and it is possible to improve their performance with appropriate design strategies. The modifications include solar protection in windows and a good orientation improve thermal behavior to a small degree: hence, it is necessary to use these together with other solutions focused on using materials in walls and roofs with more appropriate thermal properties to produce significant improvements.

Keywords: Low cost housing, Comfort, Energy, Simulation, Hot humid climate.

SIMULACIÓN DEL COMPORTAMIENTO TÉRMICO DE VIVIENDAS DE BAJO COSTO EN VENEZUELA PARA MEJORAR EL CONFORT TÉRMICO

RESUMEN

Este trabajo tiene como objetivo estudiar el comportamiento térmico de viviendas de bajo costo construidas en varias regiones de Venezuela, y discutir su adaptabilidad a las condiciones climáticas. Para ello se realizaron simulaciones en tres importantes ciudades localizadas a diferentes altitudes: Caracas (880 m), Maracaibo (40 m) y Mérida (1500 m), con la ayuda del programa ArchiPak™ desarrollado por el Dr. Steven Szokolay. Con frecuencia los ocupantes de estas viviendas se quejan del bajo nivel de confort térmico, especialmente en las zonas de clima cálido-húmedo, el cual prevalece en las ciudades y regiones más habitadas de Venezuela. Como solución los propietarios realizan modificaciones basadas en la instalación de equipos de aire acondicionado la cual está acompañada de costos adicionales de adquisición y mantenimiento de los equipos, así como también de consumo de energía, que contradice el concepto de vivienda de bajo costo y que además conspira contra la calidad ambiental. Los resultados muestran que a baja altitud la temperatura interior está por encima de la zona de confort casi todo el año. En medias y grandes altitudes la temperatura interior está bastante cerca de la zona de confort y es posible mejorar su comportamiento con estrategias de diseño apropiadas. Las modificaciones que incluyen protección solar en ventanas y una buena orientación mejoran la calidad térmica en cierta medida, y son complementadas favorablemente por el uso de ventilación natural con 1 y 1,5 m/s. En conclusión, la calidad térmica de estas viviendas se puede mejorar con el uso de técnicas pasivas de refrescamiento, pero es necesario profundizar el estudio acerca del uso de materiales en techos y paredes con propiedades térmicas más apropiadas para cada zona climática.

Palabras clave: Viviendas de bajo costo, Confort térmico, Energía, Simulación, Clima cálido-húmedo.

INTRODUCTION

A very important part of the Venezuelan population lives near the Caribbean coast where the climate is warm and humid almost the whole year. Because poor people represent a very important percentage of the total population (about 26 million), the government traditionally have provided economical and technical support to them through dwelling programs based on low interest loans. The INAVI (National Housing Institute) has been in charge of designing and building these dwellings based on economical criteria; hence quality is second class, especially thermal comfort, acoustics and lighting. Frequently the occupants modify the original design in order to improve their performance, and one of the most common solutions is installing air conditioning equipment. Its design is very simple and it is built with materials and components easily found in local stores. The house chosen in this study (INAVI, 2001) has the same specifications as any location, without taking into account the climatic differences as a result of altitude. In this work a simulation tool is used to study thermal performance with passive cooling of a low cost houses in three important cities located in different climatic zones and to discuss the best solutions to improve the thermal comfort of the occupants. This work is part of wider research carried out by the author (Sosa and Siem 2004, 2005) on building thermal performance in different climatic zones in Venezuela that includes multistorey residential and commercial buildings. It is also an approach towards a design guide for low cost passive houses in Venezuela, based on the climatic characteristics of each zone and it could be an important contribution to fulfill the lack of standard of thermal performance (ENELVEN, 2005). Venezuela has been characterized by the bad habits of energy consumption in the population, because of the availability and low cost of energy resources (oil, gas and hydroelectric power). A change in the thermal performance of this house will have an impact in the population in many ways: thermal comfort, economical and energy saving.

METHODOLOGY

This study is based on simulations of a low cost house, with the original specifications of design defined by the INAVI, known by the name Chaguaramas, in August, the warmest month in Venezuela. The climatological data correspond to three important cities of Venezuela, located in climatic zones identified by their altitude: Caracas (1000 m), Maracaibo (40 m) and Merida (1500 m). The house's main façade which has the greatest opening surface was oriented north. Based on these results and in function of the passive cooling strategies pointed out by the psychrometric chart, some measures related to the shading on windows and the roof components were taken to improve the house's thermal performance. The results were analyzed to evaluate the impact of these improvements in relation to the thermal comfort of the occupants and the potential saving of energy, in case that active cooling is used. These results were also useful to estimate the adaptability from this design to each climatic zone included in this study. Simulations were done with ArchiPak version 5.4, software developed by the Dr. Steven Szokolay, which presents important advantages because of its friendliness and complete database information.

VENEZUELAN CLIMATE

Venezuela is located between 1° and 13° north latitude, with a varied geography that includes coasts, flat lands, high savannas and mountains that reach near 5,000 m of altitude. Although Venezuela lies wholly within the tropics, its climate varies from tropical humid to alpine, depending on the elevation, topography, and the direction and intensity of prevailing winds. Seasonal variations are marked less by temperature than by rainfall. Several climatic classifications have been developed based on different approaches that have taken into account some factors such as water masses, rainfall, vegetable basement and topography. The classification proposed by Koppen (Hobaica *et al.* 2002) tries to gather all the factors, constituting an exhaustive division that considers diverse climate types: rainy tropical forest, savanna, semi-arid, height tropical, height rainy and perennial snow. A classification carried out in the Central University of Venezuela by Hobaica (Sosa and Siem, 2004) is focused in urban areas, where the microclimate is influenced by the builtup environment. The climatic zones were demarcated on the basis of the air temperature that is the variable that changes most throughout the Venezuelan geography; because solar radiation and humidity vary little. This fact is justified because most of the Venezuelan population (near 90%) lives in cities whose altitude varies from sea level to 1000 m, while 10% of them live between 1000 and 3000 m. The zone classification made by Hobaica was based on the meteorological data of 29 stations contained in the publications of the Meteorology Service of the Venezuela Defense Ministry. This macro-classification is the first approach to define design recommendations adapted to the climate and to suggest more efficient systems of environmental control from an energy efficiency point of view (Table 1).

Table 1. Classification of climatic zones in Venezuela.

Classification	Altitude (meters)
Zone I	0 - 500
Zone II	500 - 1000
Zone III	1000 - 1500
Zone IV	Above 1500

Source: (Sosa, Hobaica, Siem, Rosales, 2002)

Figure 1. Climatic zones in Venezuela.

METEOROLOGICAL DATA

The meteorological information used in this work has been obtained from the Meteorological Service of the Venezuelan Air Force. This data corresponding to year 2001, include hourly measures of maximum and minimum temperatures; relative humidity; wind speed and direction; global, direct and diffuse irradiation.

PASSIVE COOLING POTENTIAL

During the first steps of building design it is necessary for the participants of the project to choose a cooling technique that ensures a sufficient degree of comfort and to evaluate the energy consumption and the energy gain due to the use of a passive cooling technique. Several methods offer more or less precise information about thermal building behavior and the evaluation of buildings equipped with passive cooling systems. Givoni and Szokolay developed a method to define from the Psychrometric chart areas of comfort in function of different passive cooling strategies.

This approach provides useful qualitative information for architects and building designers on the feasibility of a passive cooling technique based on comfort aspects. Nevertheless, it is necessary to quantify the potential of each cooling technique and to calculate the energy gain achieved by using a passive cooling system. In previous works (Belarbi and Allard, 2001; Hobaica *et al*. 2002) simulations aimed to evaluate the climatic potential of some

of passive cooling techniques were made as a way for setting down the basis for their application in accordance with Venezuela's varied climate. The first estimates provided promising results in order to complement design strategies for obtaining suitable levels of comfort while reducing energy spending. The methodology used in these works follows a simplified procedure based on valuation indexes developed by the University of La Rochelle in the framework of the European projects Pascool/Joule and Altener/Sink. This procedure gives the necessary information for developing design tools that could be used to improve indoor comfort at reasonable energy costs. For each studied passive cooling system, it is possible to define evaluator factors which characterize the climate conditions, the nature of the technique, potential of the sink and the building type. These factors allow comparison of the different passive cooling techniques potential. Knowing the characteristics of the used fluid properties and of the natural source of cooling, called the sink, evaluator indexes dealing with the cooling potential of passive systems could be defined. For passive cooling systems which operate with the same air mass flow rate and the same fluid (air), an index is defined, IPTheoretical, of comparison of the theoretical potential that depends only on the sink by $TSink(t)$ and the climate of the site by $TInlet(t)$, $IPTheoretical = [TInlet(t) - Tsink(t)]dt$ measured in degree-hours (°h). The simulation results (Hobaica *et al*. 2002) the potentials of passive cooling in six Venezuelan cities located in different climatic zones were estimated based on degree-hours calculation as a complementary approach of thermal building evaluation. They were considered respectively, a temperature of design of 25 °C and a relative humidity of

75%. These results are related to a line of research at the Central University of Venezuela, which aims to explore the possibilities of the use of different cooling strategies to create an Atlas of Passive Cooling Strategies that serves as guide for architects, engineers and builders when making design decisions. In that work strategies of direct and indirect evaporation, radiant cooling and buried tubes were explored and their potential were calculated as shown in Figure 2.

This information helps us search for the most appropriate strategies for each climatic zone and to deepen the search of appropriate solutions to each climatic condition. When analyzing these results it is possible to verify that concerning the systems of buried tubes and radiative cooling a total covering is possible for Caracas, Maracaibo and Mérida, while the evaporative cooling strategy is not appropriate for Maracaibo. The main aim of this paper is to fine tune this study by applying the theory to specific cases.

BUILDING DATA

The Chaguaramas House, shown in Figure 3, is one of the most popular houses built by INAVI (Housing National Institute) because of its dimension and cost. It has been designed with the minima requirements that accomplish the national housing system. It has the necessary space for a family of five. It has a parking area and a garden to the front, and to the bottom a courtyard where the housing can grow in horizontal form in the future according to needs and possibilities. Other data are: total land area: 200 m² (10 mx20 m); house area: 68 m² approximately; steel structural system; walls: hollow bricks of 20 x 30 x 10 cm; floors: slab on ground; windows: metal frame, single clear 6 mm glass; doors: metal frame, inset panels; pitched roof: tiles, asphalt, timber deck 1½ cm.
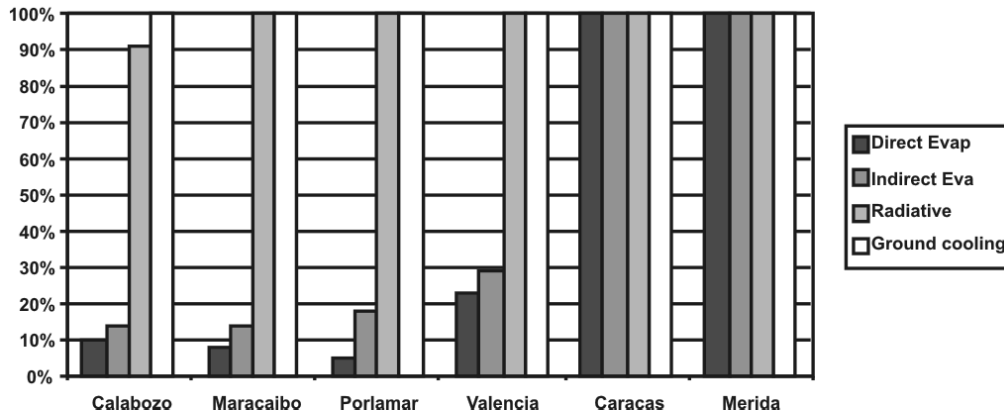
Source: (Hobaica, Allard, Belarbi, Rosales, 2002)

Figure 2. Covering of passive cooling potential in Venezuelan cities.
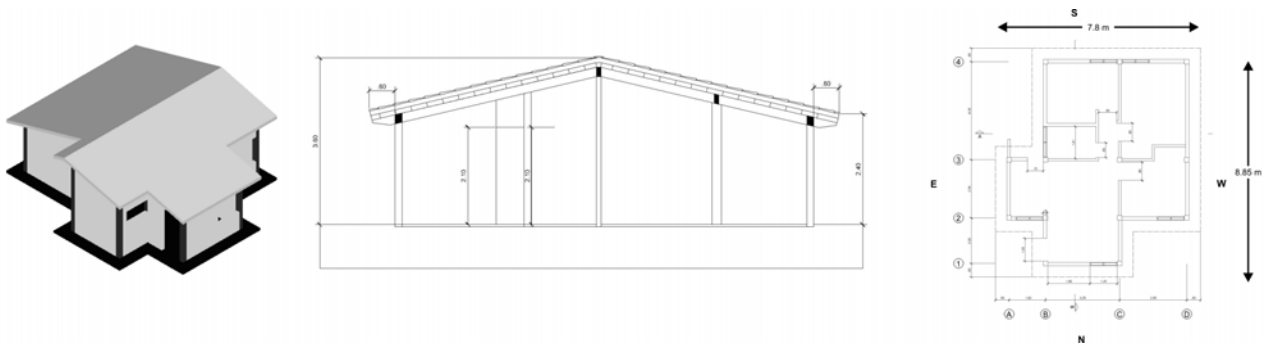
Source: (INAVI, 2002)

Figure 3. Chaguaramas House: isometric and plane view.

SIMULATION CONDITIONS

Simulations were running for a complete year (2001) based in the data from the Venezuelan Air Forces. The house was oriented with the main façade to the North. Facades north and south have the largest window surface. The data of the materials and components were obtained from the technical specifications which appeared in the INAVI official documents. Other information is: 5 family members, interior volume of 154 m3, rate of 3 air change per hour, a gain of internal heat estimated in 300 w. The warmest month in Venezuela (August) was chosen to compare the results of the three cities. In each city two case studies were also defined: original components and improved proposal; whose properties appear in Table 2.

STUDIED CITIES

Three cities have been selected in this study, located at different altitudes in order to obtain a wide spectrum of results that allow extrapolation to other cities of the country. These are: Caracas, capital of Venezuela, 4.5 million inhabitants, 880 - 1000 m altitude; Maracaibo, second city, center of the oil industry, 2.0 Million inhabitants, 40 m altitude; Merida, city located in the mountain chain of The Andes, important university and tourist center, 300,000 inhabitants, 1500 - 1700 m altitude. The 2001 climatic data are shown in Tables 3, 4 and 5.

Table 2. Building data.

			BUILDING DATA					CONDITION = ORIGINAL							
	Volume (m3) = 154				Ventilation rate (ac/h) = 3				Internal gain (w) = 300				Position = normal		
No 1	typ 2	cod 3	prent 4	orient 5	length 6	W/H 7	U 8	AU 9	sgf 10	Rso 11	abs 12	Y 13	decr 14	tlag 16	asg 17	AY 18
1	f	32	0	-1	7.8	6.8	0.79	41.7	-	-	-	6.00	0.00	0.0	-	318.2
2	w	03	0	360	7.8	2.6	2.14	36.2	-	0.06	0.50	4.51	0.49	6.4	-	92.5
3	o	30	2	360	2.4	1.5	6.00	21.6	0.76	-	-	6.00	-	-	0.64	21.6
4	w	03	0	90	8.9	2.9	2.14	47.9	-	0.06	0.50	4.51	0.49	6.4	-	113.8
5	o	30	4	90	1.2	0.6	6.00	04.3	0.76	-	-	6.00	-	-	0.64	04.3
6	o	90	4	90	1.0	2.1	3.24	06.8	0.60	-	-	3.24	-	-	1.00	06.8
7	w	03	0	180	7.8	2.6	2.14	33.8	-	0.06	0.50	4.51	0.49	6.4	-	90.8
8	o	30	7	180	2.4	1.2	6.00	17.3	0.76	-	-	6.00	-	-	0.64	17.3
9	o	90	7	180	0.7	2.1	3.24	04.8	0.60	-	-	3.24	-	-	1.00	04.8
10	w	03	0	270	8.9	2.9	2.14	54.0	-	0.06	0.50	4.51	0.49	6.4	-	113.8
11	r	40	0	-1	6.8	7.8	2.55	135.3	-	0.04	0.50	2.58	1.00	0.3	-	136.8
			BUILDING DATA					CONDITION = IMPROVED							
No 1	typ 2	cod 3	prent 4	orient 5	length 6	W/H 7	U 8	AU 9	sgf 10	Rso 11	abs 12	Y 13	decr 14	tlag 16	asg 17	AY 18
3	o	30	2	360	2.4	1.5	6.00	21.6	0.23	-	-	6.00	-	-	0.19	21.6
11	r	44	0	-1	6.8	7.8	0.34	18.1	-	0.04	0.50	1.52	0.96	1.9	-	80.6

Table 3. Climatic data for Caracas.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
latitude: 10.5 °N; longitude: - 66.9; altitude: 865 m													
T. max	23.12	23.89	23.93	27.40	27.86	25.90	26.35	27.63	26.71	26.61	25.15	25.58	degC
SD. max	1.28	1.69	1.81	1.30	1.06	0.92	0.80	1.01	1.38	0.96	1.21	1.30	K
T. min.	15.55	15.50	15.82	17.74	19.45	19.16	18.95	19.84	19.00	18.95	18.01	16.57	degC
SD. min	1.48	1.26	1.27	3.51	0.93	0.85	0.77	0.87	1.31	0.80	1.14	1.27	K
T.av	**18.78**	19.02	19.33	21.8	22.82	21.85	21.87	**23.07**	22.33	22.14	21.00	21.27	degC
RH. am	71.68	71.46	76.19	72.90	79.00	80.13	80.23	74.52	75.33	75.74	78.80	70.81	%
RH. pm	48.48	40.89	46.29	39.93	43.29	51.17	45.58	42.42	52.40	49.68	65.17	45.84	%
Rain.	16	25	10	131	29	39	120	106	171	198	49	199	Mm
Irrad.	4375	4586	4945	5052	4287	5101	5258	5940	4699	4249	4177	3780	Wh/m^2

Table 4. Climatic data for Maracaibo.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
latitude: 10.6 ° N; longitude: - 71.7; altitude: 40 m													
T. max	30.80	31.19	31.35	32.76	32.74	33.35	33.74	34.02	32.52	32.66	31.79	32.25	DegC
SD. max	1.55	1.34	1.31	1.10	0.86	1.10	1.06	1.20	1.06	1.30	1.36	0.98	K
T. min.	22.51	23.28	23.68	24.79	25.14	25.19	24.77	25.11	24.32	24.54	23.90	23.23	DegC
SD. min	1.14	1.03	0.73	0.67	0.86	0.95	0.83	1.31	1.17	0.81	0.92	1.18	K
T.av	**26.09**	26.56	26.91	28.06	28.22	28.80	28.56	**29.25**	27.92	27.98	27.29	27.08	DegC
RH. am	76.32	70.68	69.81	68.80	74.26	69.03	69.71	70.39	80.17	81.35	78.93	74.61	%
RH. pm	59.00	55.75	53.81	54.43	60.13	54.80	53.29	54.10	60.97	59.87	61.50	55.19	%
Rain.	0	0	0	41	121	55	30	131	291	142	43	-9	Mm
Irrad.	4297	4503	4857	4963	4212	5009	5165	5832	4615	4273	4103	3714	Wh/m^2

Table 5. Climatic data for Merida.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
latitude: 8.6 ° N; longitude: - 71.3; altitude: 1498 m													
T. max	25.24	25.09	25.71	25.47	26.73	25.70	26.16	27.72	26.69	26.25	25.38	25.45	degC
SD. max	0.58	0.99	1.39	1.82	1.58	1.65	1.16	1.76	0.87	1.27	1.23	1.29	K
T. min.	14.01	14.63	16.04	16.41	17.21	16.37	16.35	16.96	16.51	17.05	16.22	16.15	degC
SD. min	0.87	0.97	0.90	0.75	0.86	0.74	0.56	0.70	0.69	0.63	0.88	1.10	K
T.av	**19.13**	19.18	20.28	20.15	20.86	20.39	20.51	**21.38**	20.66	20.75	19.99	20.09	degC
RH. am	54.68	58.04	54.84	56.30	60.26	60.33	59.42	55.81	55.57	63.23	56.57	58.32	%
RH. pm	42.61	44.61	50.29	51.97	51.52	51.43	45.39	41.55	45.07	52.19	50.97	50.19	%
Rain.	67	215	64	156	109	168	102	307	182	209	160	110	mm
Irrad.	4814	4779	4707	4410	4185	4280	4622	4623	4749	4426	4324	4049	Wh/m^2

RESULTS

The psychometric diagram allows us to study the relationship between the climate of each one of the cities, the comfort zones and the potentials of passive cooling strategies. The results obtained from ArchiPak can be analyzed in Figures 3 to 5.

Results for Caracas

The Mahoney Tables obtained from ArchiPak offer the following design recommendations to Caracas: orientation north-south (long axis east-west), compact estate layout, no cross ventilation required, large opening sizes: 50-80% of wall surfaces, full permanent shading, rain protection required, lightweight walls and floors construction: of low thermal capacity, lightweight roof construction: well insulated, adequate rainwater drainage is important. ArchiPak use the Control Potential Zone (CPZ) method to show in the Psychrometric chart the relationship between climate and passive cooling strategies to building design. According to Figure 5, the temperatures in Caracas are below the upper limit of comfort temperature (Tu) almost the whole year. The same figure shows the possibilities of employing the cooling effect of the air movement to improve the thermal comfort if necessary.

Simulations made with the original conditions and an improved version based on a shading coefficient of 0.3 and a proposal solution to the roof with a reflecting foil and a better insulation, are shown in Figure 4. According to these results the maximum temperature reached in the original house (37.9 °C) is too high in comparison to the comfort temperature (27.25 °C), but in the improved version the maximum temperature is 32.1 °C which is very close to the extended limit of comfort temperature with an air movement of 1.5 m/s (32.35 °C) shown in Table 6.

A comparison of the annual load requirements in Caracas between the original house and the improved version is found in Table 6. The potentiality of energy saving (kWh) is 65% in controlled mode and a reduction of 65% K.h in free-running mode.
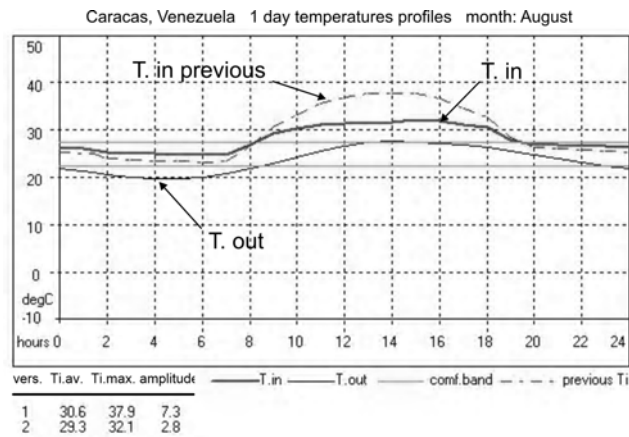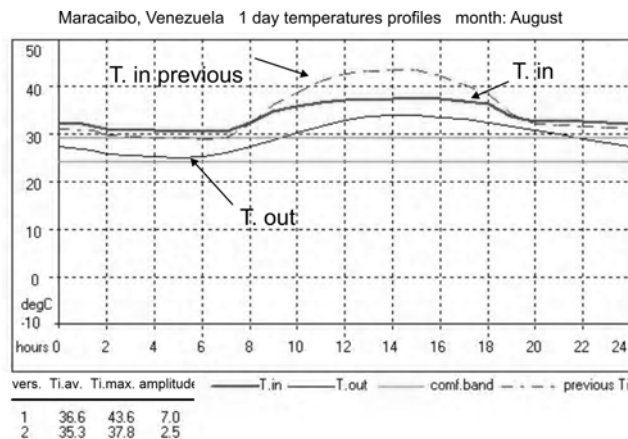

Figure 4. Temperatures profiles for the original house and an improved version in Caracas.
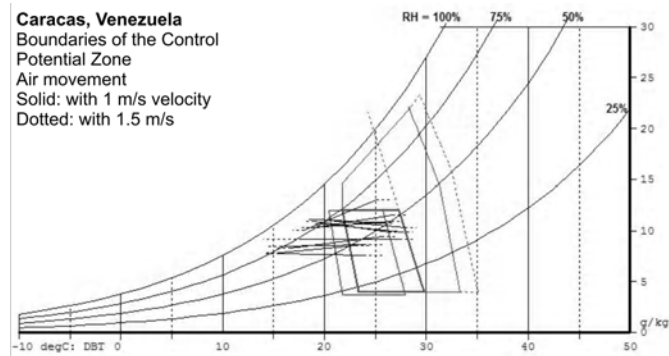
Figure 5. CPZ for the cooling effect of the air movement in Caracas.

Table 6. Annual temperatures for Caracas.

	Tu=27.25 °C; T1m/s= 31.05 °C; T1.5m/s= 32.35 °C					
	Environmental Temperature			Dry Bulb Temperature		
	Ti.av	Ti.máx	Amplitude	Ti.av	Ti.máx	Amplitude
Original	30.6	37.9	7.3	27.8	33.3	5.5
Improved	29.3	32.1	2.8	26.9	29.0	2.1
Difference	1.3	5.8	4.5	0.9	4.3	3.4

Table 7. Annual load requirements for Caracas.

	Controlled mode (kWh)		Free-running mode (K.h)	
	Heating	**Cooling**	**Underheated**	**Overheated**
Original	4652	4022	1384	11815
Improved	3854	1397	336	4100
Difference	798	2625	1048	7715
%	17	65	76	65

Results for Maracaibo

The Mahoney Tables obtained from ArchiPak offer the following design recommendations for Maracaibo: orientation north-south (long axis east-west), open spacing to allow for breezes, single banked rooms for full cross-ventilation, large opening sizes: 50-80% of wall surfaces, opening in N and S walls: body level on windward side, full permanent shading, light weight walls and floors construction: of low thermal capacity, light roof construction: reflective surface and cavity between roof and ceiling. According to the Figure 7, the temperatures in Maracaibo are always above the upper limit of comfort temperature (Tu). The same figure shows the possibilities of employing the cooling effect of the air movement to improve the thermal comfort as the main design strategy.

Simulations made with the original conditions and an improved version in Maracaibo are shown in Figure 6. According to these results the maximum temperature reached in the original house is 43.6 °C and in the improved version is 37.8 °C. Both of them are far from the extended limit of comfort temperature with an air movement of 1.5 m/s (34.27 °C) shown in Table 8. It means that a further research is needed to consider new materials and components, important changes in design and finally, an active or hybrid cooling system.

A comparison of the annual load requirements in Maracaibo between the original house and the improved version is found in Table 9. The potentiality of energy saving (kWh) is 29% in controlled mode and a reduction of 26% K.h in free-running mode.

Figure 6. Temperatures profiles for the original house and an improved version in Maracaibo.
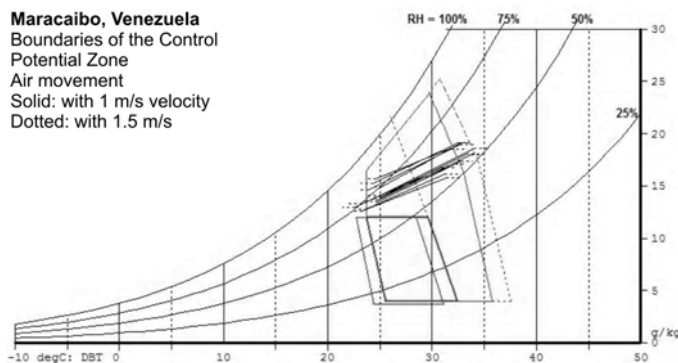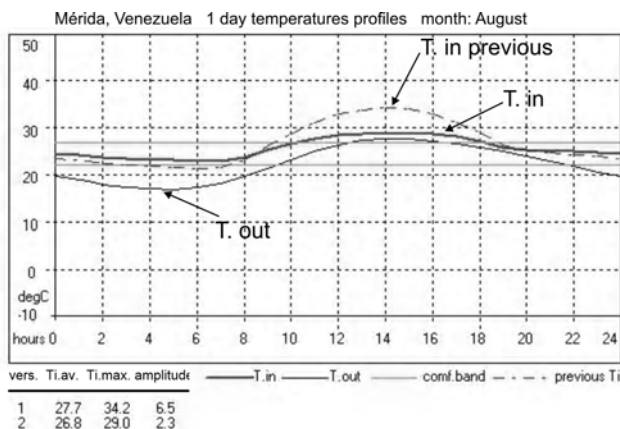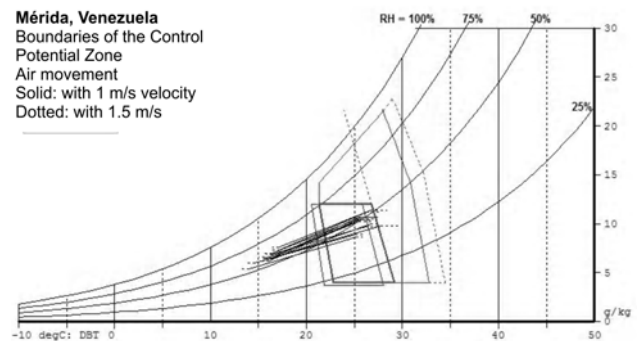

Figure 7. CPZ for the cooling effect of the air movement in Maracaibo.

Table 8. Annual temperatures for Maracaibo.

	Tcomfort=29.17 °C; T1m/s=32.98 °C; T1.5m/s=34.27 °C					
	Environmental Temperature			Dry Bulb Temperature		
	Ti.av	Ti.max	Amplitude	Ti.av	Ti.max	Amplitude
Original	36.6	43.6	7.0	33.9	39.1	5.2
Improved	35.3	37.8	2.5	33.0	34.8	1.8
Difference	1.3	5.8	4.5	0.9	4.3	3.4

Table 9. Annual load requirements for Maracaibo.

	Controlled mode (kWh)		Free-running mode (K.h)	
	Heating	Cooling	Underheated	Overheated
Original	0	11626	0	34021
Improved	0	8304	0	25275
Difference	0	3322	0	8746
%	0	29	0	26

Results for Mérida

The Mahoney Tables obtained from ArchiPak offer the following design recommendations for Mérida: orientation north-south (long axis east-west), compact estate layout, no cross ventilation is required, opening sizes: medium 30-50% of wall surface, full permanent shading, walls and floors construction: heavy over 8 hours time-lag, roof construction: lightweight, well insulated, adequate rainwater drainage. According to the Figure 9, the temperatures in Mérida are always below the upper limit of comfort temperature (Tu). The same figure shows the possibilities of employing the cooling effect of the air movement to improve the thermal comfort if necessary.

Simulations made with the original conditions and an improved version in Mérida are shown in Figure 8. According to these results the maximum temperature reached in the original house is 34.2 °C and in the improved version is 29.0 °C, which is below the extended limit of comfort temperature with an air movement of 1 m/s (30.52 °C) shown in Table 10. It means that it is quite easy to get the comfort zone with little changes.

A comparison of the annual load requirements in Mérida between the original house and the improved version is found in Table 11. The potentiality of energy saving (kWh) is 64% in controlled mode and a reduction of 80% K.h in free-running mode.

Figure 8. Temperatures profiles for the original house and an improved version in Mérida.

Figure 9. CPZ for the cooling effect of the air movement in Mérida.

Table 10. Annual temperatures for Mérida.

	Tcomfort=26.72 °C; T1m/s=30.52 °C; T1.5m/s=31.82 °C					
	Environmental Temperature			Dry Bulb Temperature		
	Ti.av	Ti.max	Amplitude	Ti.av	Ti.max	Amplitude
Original	27.7	34.2	6.5	25.7	30.5	4.8
Improved	26.8	29.0	2.3	24.9	26.6	1.7
Difference	0.9	5.2	4.2	0.8	3.9	3.1

Table 11. Annual load requirements for Mérida.

	Controlled mode (kWh)		Free-running mode (K.h)	
	Heating	Cooling	Underheated	Overheated
Original	9584	1158	2178	2456
Improved	7941	415	218	479
Difference	1643	743	1960	1977
%	17	64	90	80

DISCUSSION

Analyzing the results corresponding to the three cities it's possible to appreciate big differences in potentialities for passive cooling. This remark reinforces the observation about the inadequacy of the same house design for different climatic zones in Venezuela. It is interesting to observe that the temperature in Merida stays below the temperature limit of the comfort zone 55% of the time, while Maracaibo never reaches temperatures below this same limit which is a measure of potentiality of using passive cooling techniques for improving the thermal performance.

Reviewing the curves of temperature in August, it could be noticed that in Caracas the Ti.max is 37.9 °C and that it decreases at 35°C, a reduction of 2.9°C, applying a shading factor of 0.3. In the case of Maracaibo these values are 42.9 °C and 40 °C, a reduction of 2.9 °C. In the case of Merida, the values are 33.7 and 31.7, a reduction of 2 °C. As a conclusion it could be said that applying other more appropriate strategies to each climatic region could achieve a better thermal behavior by these houses and to offer the comfort required to their occupants. It should take into account that this will be achieved in a simpler way in the case of Merida and also in Caracas because the climatic conditions would allow it. In the case of Maracaibo the solutions are more complex because the high values of temperature and humidity restrict the application of passive cooling; the most suitable solution according to the psychometric diagram is increasing the natural or mechanical ventilation. It would be necessary to also consider the use of the active-passive hybrid cooling. Concerning the annual load requirements for cooling is noticeable that Maracaibo has very high values in both cases: 11626 kW (original) and 8304 kW (improved), which represent an important issue to the energy saving plans. As presented by the simulations it is very difficult to reach the comfort zone even with air movement. The big differences related to the results obtained for Caracas (4022 and 1397 kW) and Mérida (1158 and 415 kW), where it is possible to get the comfort zone almost the whole year, show the inadequacy of this design in the low altitudes zones. It is important to remark that the majority of the Venezuelan population lives in this zone.

CONCLUSIONS

The results of the simulations allow the inference that the thermal performance of the Chaguaramas House is different in each climatic zone considered in this study; hence it has a different level of architectural adaptability to the climatic conditions. The temperatures reached in the original version are too high in the three climatic zones included in this study and they are above the comfort temperature during the warmest month (August). The improved version offer an appropriate level of thermal comfort to the occupants that live in areas located in high altitude like the city of Merida (1500 m). In the case of Caracas, which is in a middle altitude (880 m), comfort is achieved during the coldest months (November, December, January, February) and almost completely in the warm months (June, July, August). In the case of Maracaibo (40 m), comfort is not achieved during any time of the year. The main problem comes from the climatic conditions because the very high readings of temperature and humidity allow the use of few strategies. The ventilation is an important help in this case, hence a good solution could be a combination of new materials and components for walls and roofs that improve the thermal behavior of the housing, and the use of the natural and

mechanical ventilation. It should be explored in another investigation, to take additional measures that could change the design of the house, that which was not in the objectives of this work. Among these measures it can be considered: to use more appropriate materials to warm climate in walls and roofs, to increase the window area to favor the ventilation, to modify the basic design and to propose specific solutions according to the orientation, to use mechanic ventilation if the area where the housing is located doesn't have air currents. These first results confirm the initial assumption concerning the inadequacy of this design and they allow to tune the next works on dwellings and multistory residential buildings.

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