THERMAL EVALUATION OF STRATEGIES FOR AN ADEQUATE HOUSING IN ARID ZONES AND THEIR IMPACT ON ENERGY SAVING

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ABSTRACT

Located in an extreme arid natural environment, the city of Mexicali has confronted maximum temperatures of 54°C during summertime. The high dependency of electromechanical systems use, in order to achieve interior spaces comfort is predominant, even when this represents a negative impact on economy given for the highest cost of its energy consumption requirements. This work presents the results of a representative housing simulation with the application of two environmental adequation strategies: roof insulation and walls material construction change. The thermophysical housing behavior defines the efficiency level of these strategies and their energy saving impact.

INTRODUCTION

To assure an adequate housing for everyone, as well as develop Sustainable Human Settlements to improve the environment we live, are a shared compromise of the international community and confirmed as the main objectives of The United Nations Conference about Human Settlements and the Habitat Program of the Istanbul Declaration (ONU: 1996).

The actions of preserving the environment and improving the quality of life adopt today sustainable modes to prevent the negative impact on the environment, and preserving the capacity of the ecosystems. Therefore, to develop the offer of adequate affordable housing in harmony with the environment allows the life quality improvement.

In order to find the best ways for a better life quality level through the environmental adequation, the degree of attention on these issues becomes fundamental for the development of extremely hot arid zones like the city of Mexicali B.C. in Mexico. Located at 32°N latitude, in an extremely hot desert environment, Mexicali reaches critical weather conditions. Besides, the urban housing presents criticals environmental adequation problems.

Due to the interior spaces low comfort levels, and the high electricity consumption on summer, by the use of evaporative cooling or air conditioning systems, is worth noticing the absence of a systematic use of environmental adequation strategies in building. Among other factors, it is due mainly to the lack of knowledge about the natural environment, the characteristics and thermal properties of the materials and the efficiency of the environmental adequation strategies application.

By this, the energy high consumption to achieve comfort in living spaces prevails, even when this means a strong negative impact on the family economy since the expense of this service has to dispute with other basic subsistence factors. If the use of environmental adequation strategies is related, among other factors, to the social-economic level of the population, their application must be supported by an evaluation of their efficiency in the achievement of comfort levels and energy saving in indoor spaces. In this sence, the thermophysical behavior of the architectural enveloping must become integrated to the design process, using any of the basic methods, as the bioclimatic charts or through calculations of the enveloping thermal behavior.

Through the building simulation the efficiency of the applied environmental adequation strategies could be anticipate, for this specific case, to achieve comfort levels of indoor spaces, and energy saving in the use of artificial systems for environmental conditioning during summer time. Hence, the building simulation as an expedite procedure that integrates all of these aspects and be able to predict the future building behavior will allow to design and take the best decisions in the development and execution of private, public, and/or government dwelling construction programs.

Based on the field research results of the environmental adequation strategies predominant identification in Mexicali housing (Romero, Chan:1995), the simulation model of a representative single-family house, allow evaluate the application efficiency of two strategies: insulation on roofs and walls, and the change of construction material in walls. The evaluation is done in terms of energy saving from air conditioning systems used for cooling indoor spaces during summer.

BACKGROUND

In general, the settlement in hot arid areas assumes strong conditions for the construction of living spaces. Identified by excessive heat and inclement exposure to the sun, it is required that the shelter in these areas is designed in such a form to reduce the heat impact and provides shading. Throughout history, the concern about the weather is inherent in build to solve the comfort and protection problems. Therefore, the function of roof and walls among other factors, is essential to provide protection, a degree of insulation, to retard the heat impact, and to control heat extremes.

Countless formal studies, as well as cultural and regional solutions have been taking place throughout history to adapt housing at the characteristics of this natural surrounding. Different solutions are given in every region, some of them outstanding for the use of human and natural resources, and others remarkable for their generalization and formality of the scientific studies. It is not by chance that groups from different continents, beliefs, and cultures find similar solutions in their struggle with environments alike.

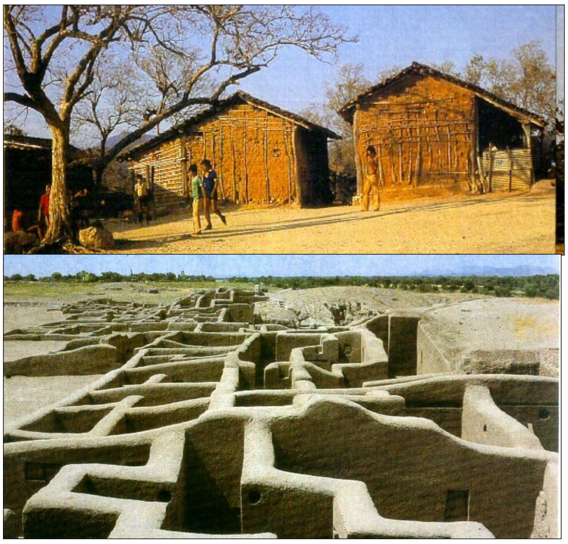

Photo 1.- Vernacular architecture in North and Northwest of Mexico

In this sense, the vernacular architecture has presented countless solutions to these extreme climatological characteristics. Among them, are the solutions in housing as we can see at Iran, Israel, Saudi Arabia, Turkey, Afganistan, Egypt, Northern Africa, Australia, Southwestern United States, North and Northwestern Mexico (Photo 1). Also, the Venezuelan and Colombian Andes housing with walls of tamped soil and the Long House at Mesa Verde in Colorado, the Acoma, Pueblo and Taos housing at North of Arizona and New Mexico U.S.A., all oriented under schemes of relationship between sun, form, climate, and landscape (Golani:1970). These solutions as authentic cultural expressions, today must be studied in order of being able to apply them as passive climate control resources, with the help of modern technology.

Actually it is convenient to remember that the best weather control is obtained through architecture adapted to the climate, applying passive and/or active systems. In the general principles of the environmental adequation by passive systems the use of the thermal conception of the enclosing, volume and mass in construction materials, accumulative walls, adequate window dimensions to reduce the heat gain, minimize the effect of radiation on roofs, interior patios, vegetation and water for cooling, sun control, and the use of natural ventilation, are considered main environment adequation strategies. And must be considered as an integral part of the design and construction of buildings.(Camous-Watson: 1983). To apply this strategies in summer time, must be implemented to fight heat gain and to facilitate heat loss in buildings.

Nowadays, roof and walls –among other factors- are still the essential elements to provide comfort in interior spaces, through the application of environmental adequation strategies. Therefore, their form and material are related directly to the thermophysical behavior of the enclosing. Koenigsberger, Mahoney and Evans recommend high reflecting, heat flow resistant materials, that also have low-emission in internal surfaces, as adequate materials for roofs in hot arid zones. Also, the materials for exterior surfaces must have low thermal absorption and high emissivity. (Puppo: 1976).

If the building's enclosing acts as a filter between the external and internal conditions, the wall must control correctly by itself the effects due to air, temperature, wind and the heat radiation that must be blocked effectively before it reaches the building's enclosing (Olgyay: 1998). The external heat impacts trespass the external enclosing of the building before affecting the inner temperature, so the first heat control layer is the surface. Due to this, the selection of absorption and emission is basic for an effective defense against the radiation impacts on the building.

Considering that the daily variation of the calorific load oscillates in the interior of the material under the global coefficient of heat transmission and the specific volumetric heat, the most important characteristic for thermal control in materials, is their behavior in the calorific transmission. An effective way to reduce the heat flow is using the insulation properties of the material.

Photo 2.- Mexicali housing: concrete roof and concrete block walls

MEXICALI HOUSING CHARACTERISTICS

Based on the results of a previous field research (Romero, Chan: 1995) to identify the predominant environmental adequation strategies in the Mexicali housing, define that in 1990, the roof-walls systems, were using: 34% wood-brick, 28 concrete-block, 18 wood-adobe, 11 concrete -brick, and 9% wood-block. The tendency to use concrete roof and concrete block walls has increased (Photo 2).

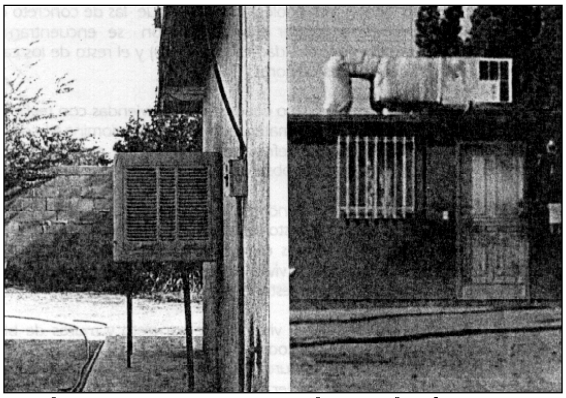

Photo 3.- Evaporative cooling and refrigeration systems

Regarding electromechanical air conditioning systems: 66% of the houses use evaporative systems and were related to the use of brick walls and wooden roofs. The other 34% with refrigeration systems were housings of concrete block walls and concrete roofs (Photo 3).

In general, the housing present environmental adequation problems, due to the use of high conductivity materials as concrete block on walls and concrete on roofs. Also, roofs sloped at an angle that allows to capture the too much solar radiation, bigger areas facing west, the scarce exterior vegetation and until 1990 due to the low insulation percentage in housing (CFE-IIS/UABC XIII Ayuntamiento: 1992).

Beside, the Mexicali city in summer periods has registered maximun average temperatures of 44.5°C and extreme temperatures of 47.8°C like those registered on July 1997 (Table 1); and even 54°C in other periods (SAG: 1982).

Table 1.- Temperatures 1997. Mexicali B.C.

Temperatures °C	May	June	July	Aug	Sep
Temp max	44	44.5	46	47.8	46
Average temp max	40.4	44.5	42.7	43.5	39.4
Temp average	30.7	31	33.5	35.9	32.3
Average temp min	21	24	24.3	28.2	25.3
Temp min	17	16	19	24.5	20
Thermal oscilation	19.4	13.5	18.4	15.3	14.1

*Information reference: Boletín Mensual Meteorológico, Departamento de Meteorología. Instituto de Ingeniería UABC.1997

Related to this situation, the electric energy consumption in the city reaches during summer, 44% from the total consumption, and registers consumption per capita of 5.25 MG/year compared to a national level of 2.25, exceeding it in more than 100%.

In 1992, the average percentage of the family income destined for the payment of electricity during summer, -in 8 out of every 10 homes-, was 10% of the total income in a yearly median proportion, which is three times more than the national median. In homes with an income less than 2 minimum salaries the percentage was from 8 to 18 out of the annual income, and from these households 1 out of 5 destined up to 40% of its total income (CFE-IIS/UABC-XIII Ayuntamiento: 1992). This analysis reveals the efforts of the population in order to make a decision whether to reduce its comfort level without affecting its basic family economy, or to reduce the family expense in order of not reducing the environment inner spaces comfort level.

Facing this problem, the CFE implemented the Energy Saving Program of the Electrical Sector and in 1991 created the Trust for the Housing Thermal Insulation. The Mexicali Energy Saving Commission was created. Also the Architecture School, the Engineering Institute, and IIS/UABC have developed investigations about possible solutions to this situation.

Despite of this, in 1994 the residential sector consumption in Mexicali was approximately 4 times more than the national average, even the yearly consumption varies, in February is lower and increases to reach its maximum value in August, getting three times higher regarding the lowest yearly consumption. According to studies about calculations of average consumption from the month of August and the quantity of housing (Romero: 1994), it was determined that 1/3 of the housing with refrigeration systems averages has electricity consumption similar to 2/3 of the sector with evaporative cooling systems.

Photo 4.- Mexicali Dwelling Units

The relationship between the predominant housing typology and the electricity consumption, concludes that the higher energy consumption is in the concrete roof-block walls housing. Actually the use of this construction system is increasing (Photo 4).

The "Thermal evaluation of the environmental adequation strategies for the residential sector of Mexicali" study (Romero, Chan: 1995), show two types of adequation actions; those derived from official programs and the applied by the population. The predominance of the systematic application of thermal insulation on roofs in order to save energy was detected as an action from the official program of the Thermal Insulation Trust implemented by the CFE. Beside, the results from the field research in a sample of 100 houses in the same study, conclude that in order to reduce the effect of the high temperatures, 49% of the consumers carried out at least one environmental adequation action in their house. The 84% of these consumers applied thermal insulation on roofs, the rest planted trees, applied white paint on walls and built shading porches. The remaining 51% did not apply any strategy. Also, from the total of the sample, the majority assume to know the desert environment in which they live, but do not know the environment adequation and identify this with thermal insulation. In general the majority aware the energy saving benefits, and they consider that energy saving can be achieved by reducing the use of electrical appliances and lights, but they do not accept reduce the use of electrical refrigeration units.

The study conclude that even when the population of Mexicali is aware about the desert environment in which they live, about the environmental adequation and the benefits of energy saving, the residential sector remains the biggest consumer of electricity. And finally, the study proposes the implementation of other actions and mechanisms to promote a construction culture suitable to the extreme conditions of the environment.

SIMULATION

Based on the results from the study and field research, (Romero, Chan: 1995), the evaluation of their efficiency in terms of environmental comfort levels in interior spaces and energy saving is defined through the application of a model of thermal loads (SUNCODE). This simulator is an adaptive version from the SERI/RES program designed for the Solar Energy Research Institute (SERI) by its authors Larry Palmiter and Terri Wheeling. The simulator is applicable to residential buildings and small commercial sites. The technique of mathematical solution of the program is a combination of finite differences, Jacobian interaction and constant optimization. It has the advantage and flexibility to select the level of detail required, as well as the length of the analysis period.

Among the thermal behavior parameters analyzed in the simulation were:

a. The loose of energy in the relationship house-environment. It was considered stable and the calculation was done depending on the temperature difference between indoor-outdoor air, its value is expressed in Watts, and the difference is in °C.
b. Total energy storage indicated by the capacity of its components (walls, roof, floor) in kilojoules per centigrade degree of temperature registered to maintain the energy in its mass.
c. The amount of energy to remove in order to reach the temperature of design in interior spaces .
d. Maximum cooling required; based on the perceptible heat to be supplied or removed form the space through heating, ventilation or cooling equipment; and establishes the maximum requirement in kilowatts by air conditioning unit.

METHODOLOGY

The development of this study included the stages of:

a. Identification of environmental adequation principles and strategies for extreme arid zones applicable to the Mexicali housing.
b. Definition of prototype housing by economic sectors, and according to construction systems and materials predominantly used.
c. Identification of environmental adequation strategies used predominantly in the housing sector.
d. Simulation of a representative house, in order to evaluate the efficiency of the environmental adequation strategies predominantly used.

The simulation was made for the summer period, from May to September, and the temperature of the designed was 25°C at indoor spaces with refrigeration system.

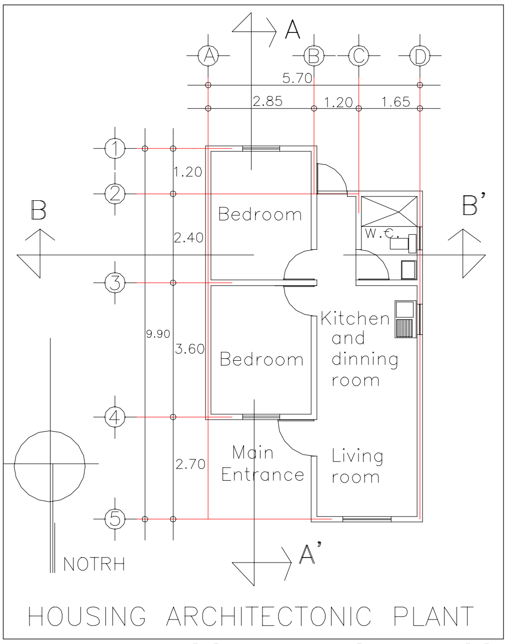

Figure 1.- Mexicali housing simulation model. Architectonic plant

The simulated house (Figure 1), has a construction of 45.2 m² and a volume of 108.48 m³. It has two bedrooms, living room, kitchen-dining room, and one full bathroom. The main facade is facing north. Walls are 0.15m thick, of concrete block with both sides without flattening. The East-West oriented, two-sloped roof is made of concrete with a 0.10m thick waterproofed with sand tile and asphaltic emulsion. The floor finish is 0.02m thick floor tile, joined with cement-sand mortar on a concrete base with 0.10m thickness. The windows have single clear glass. The illumination is incandescent. No insulation was considered in any element of the house. The internal gain was based on a family of three: father, mother, and son, considering activities divided by periods from Monday through Friday and weekends.

Two independent zones were defined: a refrigerated zone with the bedrooms, living, dining room and kitchenareas, and the bathroom as a non-refrigerated zone. In this case the evaporative system use is no considered, therefore its insufficient efficiency to achieve the indoor space comfort level in extremely climatic conditions registered in July and August. Even the minimum temperature average of June and July above 20°C, by the short period time for the outdoor-indoor radiative exchange is insufficient for the effective nocturnal cooling ventilation. This, regard to the high energy achieves on the architectonic enclosure and its indoor spaces.

Due to the lack of a local meteorological file is ASCII or binary language, required by the simulator, the meteorological file from the city of Yuma in the state of Arizona, U.S.A. was used due to its similarity of climatic conditions and characteristics of natural context with Mexicali. The temperatures yearly averages are: 22°C in Mexicali and 23°C in Yuma. Both cities are located at 32°N latitude, with a small difference of 1° on its longitude and altitudes of -4.00m in Mexicali and +0.483 in Yuma city.

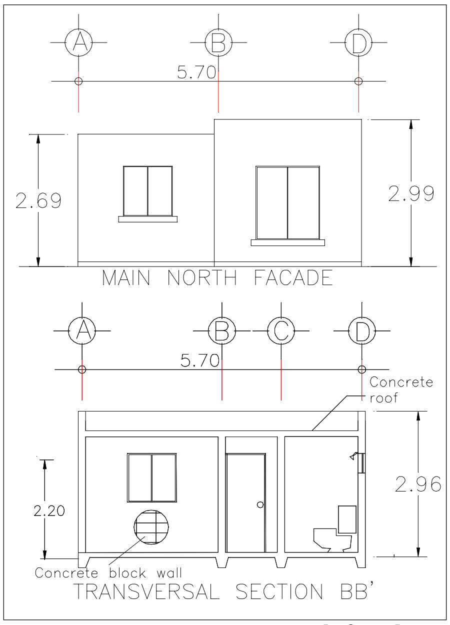

Figure 2.- Housing main North facade and transversal section

Is considered only the north-south orientation effect, with main north facade (Figure 2). Also the thermophysical properties of construction materials in walls, roofs and insulation are considered (Table 2).

Table 2.- Materials thermophysical properties

Properties	Brick	Concrete block	Concrete	Poliestire ne
Volumetric mass (Kg/m³)	1 800	2 300	2 300	16
Thermal conductivity (W/mºC)	0.72	1.08	1.44	0.037
Specific heat (J/KgºC)	829	920	865	1 220
Thermal difusivity (M²/S)	$1.7x10^{-3}$	$1.8x10^{-3}$	2.45×10^{-3}	1.15×10^{-5}
Thermal delay (Hrs)	4 hrs 38'	4 hrs 31'	2 hrs 47'	8 hrs 48'
Thermal reduction (%)	30	30	48.07	10
Thermal resistance (M² ºC/ W)	0.208	0.138	0.07	0.686

* Information reference: Estimados a partir de Rojas 1992, Instituto de Investigaciones en Materiales, UNAM

Is not considered the changes of main facade orientation, the possible increase of the family member for the housing occupancy, shading effects by the vegetation or additional exterior constructive element. Even the additional application of others housing environmental adequation strategies, also are not considered. It is aware that this aspects and actions will be in a future time the objectives of additional analysis to develop using the building simulation, in order to complement the present case of study.

The house is simulated with the application of two environmental adequation strategies; change of material in walls and application of polyestirene insulation (0.025m thick) in walls and roof.
The variations were:
1.- Change the constructive material in the walls: concrete block or brick with concrete roof
2.- In the application of insulation:
a. The entire house without insulation
b. Roof with insulation and walls without insulation
c. Roof without insulation and walls with insulation
d. Roof without insulation and West side walls with insulation
e. Roof and West side walls with insulation
f. Insulation in all the outside surfaces.

Table 3.- Simulation results of thermal housing behavior of the study case. Mexicali B.C. 1999

Variation of choice on construction material of roof-wall	Insulation	Maximum cooling require ment (KW)	Remove energy loads (GJ)
1.- Concrete Block Wall -Concrete Roof	None element	23.778	-33.975
1a.- Concrete Block Wall -Concrete Roof	Roof	17.727	-27.302
1b.- Concrete Block Wall -Concrete Roof	Wall	20.530	-29.280
1c.- Concrete Block Wall -Concrete Roof	West wall	23.355	-33.205
1d.- Concrete Block Wall -Concrete Roof	Roof and west wall	17.385	-26.764
1e.- Concrete Block Wall -Concrete Roof	Roof and all exterior walls	14.646	-23.094
2.- Brick Wall-Concrete Roof	None element	22.971	-31.967
2a.- Brick Wall-Concrete Roof	Roof	16.967	-25.369
2b.- Brick Wall-Concrete Roof	Wall	20.342	-28.467
2c.- Brick Wall-Concrete Roof	West wall	22.633	-31.434
2d.- Brick Wall-Concrete Roof	Roof and west wall	16.712	-25.053
2e.- Brick Wall-Concrete Roof	Roof and all exterior walls	14.501	-22.308

RESULTS

The results (Table 3) of this simulation of the representative house and the application of material change strategies in walls, and the use of insulation in walls and roofs indicates:
1.- Regarding the change of materials in walls, in all the variations of the analysis the maximum cooling required in the house with concrete block walls and concrete roof is higher than the cooling required in a house with brick walls and concrete roof.
2.- Regarding the use of insulation in roofs and walls:
a. The interior cooling requirement is lower if the roof is insulated, than if only the walls were insulated.
b. More interior cooling is required if the west-side walls are only insulated without the roof, than all the exterior walls are insulated without the roof.
c. A less interior cooling is required if the roof and walls are insulated, than if only the roof is insulated.
d. The interior cooling requirements are remarkably lower if roof and exterior walls are insulated.
e. With insulation on the roof, the interior cooling requirements are slightly higher than if only the west side walls and roof are insulated.
f. Due to its thermal characteristics, block is the least adequate material to be used on the housing in Mexicali, since even with the application of insulation, the interior cooling requirements are higher compared with the requirements for housing with brick walls.
g. In terms of insulation and regarding the cost of material, to insulate the roof is one of the most feasible actions, of proven efficiency in any of the options that combine block or brick walls.
h. In all the variations of the analysis, to decrease the cooling requirements implies energy saving.

CONCLUSIONS

In extreme hot arid zones like Mexicali, it is essential to apply environmental adequation strategies in building in order to decrease the interior cooling requirements, as well as to reach comfort levels in interior spaces. This to achieve energy saving in the use of electromechanical artificial systems for climate conditioning, specially during summer periods.

The simulation in buildings will allow anticipate the efficiency of the adequation strategies applicable to living spaces, making highly possible to improve the quality of life of the users. It also gives certainty on the decision making and helps to implement massive construction programs that allow offering an adequate, comfortable and decent housing, within the regional sustainable development.

The obtained results of this specific case, indicates that one of the most efficient environmental adequations strategies for arid zones, is the thermal insulation of the architectonic enclosing. This is a certainly form to achieve electric energy savings related to the refrigeration less use. Also, to avoid the use of constructive materials with higher heat conductivity level, especially on roofs and higher solar gain wall area exposition.

As a certainly form to design and build the future dwellings adequate to an extreme arid hot zones as the Mexicali natural context, the building simulation will allow support the social and economic community develop. This, through decreasing the negative impact given for the inadequacy of the future housing buildings, and the achieve of the environment preservation and the rational use of non-renewable resources.

ACKNOWLEDGEMENTS

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REFERENCES

1. Camous, R. y D. Watson, “El Hábitat Bioclimático”, ed. G.Gili, México D.F., 1983.
2. Comisión Federal de Electricidad –Instituto de Investigaciones Sociales /Universidad Autónoma de Baja California -XIII Ayuntamiento, “Encuesta sobre el grado de adecuación ambiental e impacto social derivado del consumo eléctrico en Mexicali”, Mexicali B.C., 1992.
3. DeLaHunt, M., “SUNCODE: a program user's manual”, Ecotope Inc., Seattle Washington, 1985.
4. Golani, G., “Housing in Arid Lands. Design and Planning”, Architectural Press, London, 1970.
5. Instituto de Ingeniería UABC, “Boletín Mensual” Departamento de Meteorología, Universidad Autónoma de Baja California, Mexicali B.C., 1997.
6. Olgyay, V., “Arquitectura y Clima”, ed. G.Gili, México D.F., 1998.
7. Organización de Naciones Unidas, “Declaración de las Naciones Unidas sobre Vivienda adecuada y Desarrollo Sostenible de Asentamientos Humanos y Programa Hábitat”, Estámbul, 1996.
8. Puppo, E., et al. “Acondicionamiento natural y arquitectura”, 1976.
9. Romero, R., “La vivienda representativa de Mexicali: caracterización física, social y lineamientos de adecuación ambiental”, Tesis de Maestría en Arquitectura, Facultad de Arquitectura, Universidad Autónoma de Baja California, Mexicali, B.C., México, 1994.
10. Romero, R. y D.Chan, “Evaluación térmica de las estrategias de adecuación ambiental para el sector residencial en Mexicali”, Facultad de Arquitectura, Universidad Autónoma de Baja California, Mexicali B.C., 1995.
11. Secretaría de Agricultura y Ganadería, “Normales Climatológicas”, Dirección General de Geografía y Meteorología, México D.F., 1982.

NOMENCLATURE

CFE: Comisión Federal de Electricidad
IIS: Instituto de Investigaciones Sociales
SAG: Secretaría de Agricultura y Ganadería
SERI/RES: Solar Energy Research Institute
UABC: Universidad Autónoma de Baja California
UNAM: Universidad Nacional Autónoma de México
ONU: Organización de Naciones Unidas