Architectural and economical implications in consumption of electricity on the housing sector in arid zones: the Mexicali case in Mexico

R.A. Romero[a,*], J.D. Morales[b]

[a]*Facultad de Arquitectura, Universidad Autónoma de Baja California, Mexicali, B.C., México;* [b]*Centro de Investigaciones y de Estudios de Posgrado , Facultad de Arquitectura, Universidad Nacional Autónoma de México, México*

ABSTRACT

The objective of this report is to analyse and dwell upon the climatic implications on architectural and economical issues involved in the housing sector's electricity consumption in Mexico. The residential sector in the Mexican city of Mexicali is selected as a case study due to the fact that it is highly representative of cities located in arid zones. The city has one of the high levels of per capita electricity consumption as well as one of the highest temperatures during summer. The relationship between the Residential electric energy consumption (REEC) with environmental temperature is studied during the time period between 1999 and 2000. The architectural implications are related to energy efficiency of building and construction materials commonly used, and the existing building code. The impacts of climate on human thermal comfort and the effect on the ERC are studied as well as the economical impact of the latest official decision to charge the '1E' electrical fee. The conclusion suggests that in order to reduce the REEC, efficient dwelling units and efficient cooling systems are not enough. What is necessary is to have an energy conscience dweller; therefore the promotion of a 'culture' of energy conscience becomes a paramount topic.

INDEX TERMS

Residential electric energy consumption; Architectural implications; Climatic implications; Economical implications; Arid zones; Mexicali

INTRODUCTION

Residential electric energy consumption is a very complex phenomenon due to the mixture of technical, social, economical and psychological aspects along with the environment. REEC is a consequence of the energy consumed by electrical appliances that satisfy human needs. This is a result from aspects related with: (a) climatic conditions, such as temperature and humidity; (b) physical housing conditions, such as size of household units, building materials (roofs, walls, windows, floors); (c) social aspects, family structure, size of the family, ages and lifestyles shown by the activities of the users; (d) economic aspects, associated with average income, number of incomes per family and their purchasing power that allows the acquisition of more efficient equipment; and (e) psychological aspects, related to the behaviour of people using the electrical appliances. This summarizes that REEC is the result of the interaction of climate and physical aspects, with social and economic aspects; finally, REEC exceed only the architectonic concepts.

The residential sector in the Mexican city of Mexicali is selected as a case study due to the fact that it is highly representative of cities located in hot climates. The city has at the high levels of per capita electricity consumption and one of the highest temperatures during summer.

* Corresponding author.

Architectural Implications on Residential Electric Consumption

Which are the technical resources that architects can use to minimize the impact of energy consumption? The effect of architectural implications in the REEC refers to those actions concerning the envelope of the building and interior and exterior spaces, regardless of who designed them. Architectural implications begin with the study of a building's heat gain and human thermal comfort. It is worth noting that these resources can be integrate on: (a) design management of bio-climatic principles, conditioning or building of spaces, so that housing units make best use of their environmental conditions or protect themselves from it according to its natural location; (b) applying energy conservation principles (or mandatory regulations) on building projects not limited only to thermal resistance criteria.

Bioclimatic principles are present on almost all bibliographies of every book dealing with Bioclimatic, Solar or Passive and Low Energy Architecture. These includes shape, orientation, building materials, construction systems, management of the exterior space (shades and vegetation), and natural ventilation among others, similar to those elements present in vernacular architecture. The greater or lesser heat gain will determine the mechanical equipment required to obtain comfort conditions for the user. These conditions should be uniform in the interior space, despite external climatic changes. It is worth noting that one of the most important aims should be the conservation and saving of energy.

In Mexico, energy conservation regulations for the building's envelope were approved in the year 2001 (NOM-008—ENER-2001). Therefore, at present it is difficult to find their implementation. The only operating regulation is the one dealing with energy conservation regulation for appliances (refrigerator, air conditioning packed, air conditioning room, lighting).

Economical Implications

Economical implications refer to electric energy billings made to the residential users due to a cost for electric consumption during a certain period (that increases monthly and differs in price depending on energy consumption rank).

BACKGROUND

In Mexico, the REEC was about one-fifth of the total electrical consumption during 1990 and 2000 (22.1% in 1990 to 23.3% in 2000). Furthermore, the REEC is increasing, about 50% more (1990, 20 392 GWh; 2002, 36 128 GWh). Table 1 shows a comparison made of the REEC performance during the years 1990 and 2000 nationwide. However, analysing REEC is important due to the direct impact on population that in 2000 there were more than 21 millions of residential consumers and 88.2% of consumers of the electrical sector (CFE, 2001), and in terms of dwelling houses which was 21 954 733 (INEGI, 2000).

Table 1 Electric energy consumptions in Mexico's residential sector, 1990 and 2000 (GWh)

Year	Total electric consumption (GWh)	Residential electric energy consumption (GWh)	Residential users	Per capita electric energy consumption (MWh/year)
1990[a]	92 127	20 398	14 316 889	1.425
2000[b]	155 349	36 128	21 055 344	1.716
Rate[c]	5.1%	5.05%	3.52%	

Source: [a]Comisión Federal de Electricidad, Estadísticas por Entidad Federativa (1991).
[b]http://www.cfe.gob.mx/gercom/ estadis/ secedo/ secsec/html,marzo 30, 2001.
Note: [c]Annual rate growth.

Table 2 shows the different tariffs applied to electricity consumption, proportions and the corresponding users. It is important to note that tariffs 1E and 1D are strictly for residential consumption in arid zones.

Table 2 Electricity energy consumption and users, according to residential tariff, México, 2000

Tariff	Consumption		Users		Per capita consumption (MWh/año)
	GWh	%	Thousands	%	
1	16 611	46.0	12 424	59.0	1.337
1[a]	2281	6.3	1624	7.7	1.405
1B	7871	21.8	3875	18.4	2.031
1C	3165	8.8	1489	7.1	2.126
1D	2379	6.6	750	3.6	3.172
1E	3821	10.5	893	4.2	4.279
Total	36 128	100	21 055	100	1.716

Source: CFE, Estadísticas del Sector Eléctrico Nacional 2001, 2002.

In Table 2, it can be observed that in tariffs 1D and 1E, the amount of users are less and there is a higher per capita consumption. The limited proportion of users seen on a national perspective shows that cases of arid zones, besides climate impact, have an economic impact on the fee paid for kilowatt-hour consumption. However, the impact will be considered low or high depending on the families' income levels (Sández, 1996).

The geographic and economic diverse contexts in the country are shown as well in the total electric consumption and the per capita consumption. About one-fourth of the country's total residential consumption takes place at the Mexican border with the United States (Romero, 2001). This part of the country is located at the dry climate region. The case of the city of Mexicali presents the highest per capita electricity consumption (6.3 MWh/year), and it is the only city with the two characteristics aforementioned: a border city with dry hot climate.

STUDY CASE: RESIDENTIAL SECTOR OF MEXICALI

Natural Context

The geographic location of Mexicali, situate it in the arid zones of northeast Mexico, with a type of climate BW(h')hs(x')(e'): hot dry climate, very arid with a winter rainfall pattern and with an annual oscillation in a monthly rank of extreme temperatures (García, 1981). This implies temperatures increasing from May, with maximum value in July or August (maximum average 44ºC during 1990–2000) and lower temperatures in December and January. Relative humidity, around 40–60%; besides, high potential of solar energy (1100 W/m^2 maximum in July) is a zone favoured by a no-rainfall season and bright clear skies.

Physical Characteristics of Household Types and Mechanical Equipment

According to Romero (1994), 33.8% of the typical dwelling unit in Mexicali is made of wood roofing and brick walls; 28.2% have concrete block walls and concrete roof slabs; 17.4% are made of wood roofing and adobe walls; 11.3% are made of concrete roofing and brick walls; and 9.3% of wood roofing and concrete block walls. The first two represent 62% of the typical housing. One of the main problems the residential sector presents during summer, as a consequence of climatic conditions impact, is that almost every housing unit has poor thermal condition, due to their building system (low thermal mass), inappropriate orientation, lack of thermal insulation and without an outdoor microclimate design to help improving environmental conditions, among others. All these issues force the need of mechanical equipment in order to have a comfortable temperature, such as fans, coolers and air conditioners. It is worth pointing that sometimes the climatic impact due to the materials and the construction system used causes a phenomenon called stored energy, which produces a higher temperature indoors rather than outdoors.

Electric Energy Consumption in Mexicali

Table 3 shows the annual behaviour of REEC for the years 1990 and 2000, based on the amount of consumers and the per capita consumption in Mexicali. In the local area, it implied an electric consumption increase of 50% approximately in a decade. Finally, Mexicali impact in the national field represents 1% of consumers, 5.3% of total electric consumption and per capita three to four times higher than the national average.

Table 3 Population, housing and electrical energy consumption, residential sector, Mexicali, 1990 and 2000 (GWh)

Year	Population	Housing	Energy consumption[a] (GWh)	Consumers[a]	Per capita consumption (MWh/year)
1990	601 938[b]	131 515[b]	805.302	149 270	5.39
2000	764 902[c]	190 465[c]	1352.024	224 176	6.03
Average			890.71	181 159	5.37

Source: [a]Comisión Federal de Electricidad, Departamento de Estadísticas, Mexicali (2001). [b]INEGI, Baja California, Resultados Definitivos, XI Censo General de Población y Vivienda (1990). [c]INEGI, Baja California, Resultados Definitivos, XII Censo General de Población y Vivienda (2000).

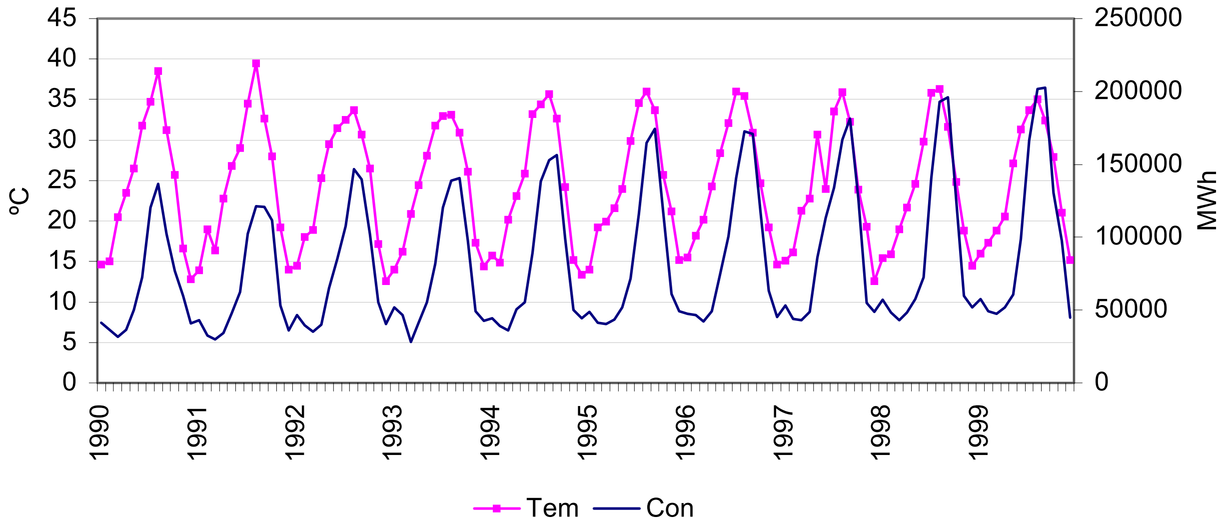
METHODOLOGY

The methodology used in this study includes climatic implications that where analysed with the inter-relation between temperature and monthly electrical energy consumption during 1990–2000. The architectural implications were determined using of Givoni’s Bioclimatic Chart, since he considers close spaces and mentions some of the requirements for passive or mechanic systems for space thermal conditioning. This method is one of the ways to inter-relate climatic/conditions, thermal comfort/adjusting and environmental strategies. Besides, local building codes were reviewed and identified, and energy conservation regulations were considered. The economic impact was studied through residential fees and the impact of the monthly billings on families’ economy.

RESULTS

Climatic Implications

There are similar cycles between temperature and energy consumption. The energy consumption has a seasonal behaviour (Figure 1).



Source: Comisión Federal de Electricidad, División Baja California y Departamento de Meteorología UABC (2001).

Figure 1 Electric energy consumption and ambient temperature, monthly average, Mexicali, 1990–2000.

Architectural Implications

The architectural implications in the consumption of electric energy are related to the fact that housing units require thermal conditioning systems in order to have a comfortable temperature. Based on temperature and relative humidity and the bioclimatic chart, it is observed that due to the summer conditions in Mexicali (May–October), regarding the critical conditions (maximum temperature average), only in 4% of the period it is comfortable; in 5% natural ventilation is required; on 16% of the days evaporative cooling is required; in 11% high thermal mass is required and in 36% high thermal mass besides night time ventilation is required. Considering that these conditions are not present in household units within the region, 28% requires an air conditioning system compulsorily. In general, if the houses in Mexicali were built with high thermal mass and with possibility for ventilation during the night, it can be assumed that the need for air conditioning will diminish and there will be comfortable temperature with the use of evaporative coolers.

In Mexicali, house building is not regulated in terms of energy saving criteria, or of environmental concern. These issues are only mentioned in the State Building Law. However, in the local Municipal Regulations the issues are not even mentioned.

Energy consumption impacts are higher in air conditioning equipment rather that in evaporative coolers. This is due to the fact that the air conditioning equipment works according to the temperature variations and the evaporative cooler keeps constant despite the temperature variations.

At present, there are some local energy saving policies (using Federal grants) for people who use air conditioning equipment, such Energy Saving Programme. This programme changes old air conditioning units for high efficiency equipment. Approximately 35% of the residential users in Mexicali are benefited (CFE, 2000). Coincidentally, there are no policies for new equipment acquisition for people who use evaporative coolers, or to improve their housing environmental conditions. In the cases where evaporative coolers are used, the use of electrical appliances, such as refrigerators and freezers, become the main source of energy consumption. Finally, the whole effects of temperature, housing physical characteristics and additional equipment acquisitions results in Mexicali having a per capita electric energy consumption three to four times higher than the national average and also higher than other residential users of the rest of the cities within the arid zone of the country.

Economical Implications

Economical implications are strongly related to energy consumption bills, families' incomes and the paying capacity of the users. Special electrical tariffs for hot climates, such as 1E and 1D, are not enough for Mexicali. First, the climate conditions because of the temperature minimum media of summer have been higher at 32°C (89.6ºF) which is the criteria used in 1E tariff. This criteria does not consider the maximum average temperature and the relative humidity criteria; and, second, because the relation between consumption rates, consumption levels and the difference in cost are not adequate.

CONCLUSIONS

There are architectural implications on the behaviour of electric energy consumption even though they have been transcended by an economic, social and cultural situation. Architectural implications are the prime point to be considered for having greater or lesser electric consumptions, since it can be reduced significantly, because requirements for thermal condition systems can diminish if the house is properly adapted to its natural environment Nevertheless, having a house properly adapted to the environment but with inefficient cooling equipment will not help save energy. In addition to this, the use of inappropriately equipment and the users' life styles will allow this phenomenon to continue. Actions are required in different areas, since this phenomenon transcends diverse fields, in which integral actions are needed, as well as the awareness and compromise of the persons involved. It is not only saying, house + efficient-equipment = energy savings. It requires consumers' awareness in the use of electric energy and incentives for those who realize it. But most important, what is needed is an 'integral energetic awareness' from politicians and those in charge of the decision-making process within the government; what is urgent is a political will to make the right decisions at the governmental level.

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