Thermal Response of Dwellings in Northwest Mexico:
Applying passive design strategies

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ABSTRACT: Sonora State in Northwest Mexico has a hot, dry climate, considered to be extreme compared even with the rest of the country. Urban dwellings in this region demand the installation of mechanical air conditioning in order to achieve comfortable thermal conditions, and this is due to building design that does not take account of the climate. Electricity consumed by air conditioning represents a significant proportion of the typical annual electricity demand in dwellings, and the cost of electricity in Mexico is relatively high compared with household incomes. Together, this means that the cost of using air conditioning can be inhibiting, leading to fuel poverty. This article describes the climatic and economic background of Sonora to identify the need for principles of passive design to be applied to residential buildings. Thermal modeling is being carried out to identify construction strategies that minimize the need for mechanical air conditioning.
Keywords: energy, comfort, hot climate, passive cooling.

INTRODUCTION

Thermal systems installed in dwellings to create comfortable, safe and healthy environments demand the consumption of electricity. In Sonora State, Mexico, these are primarily air conditioning systems. This has a large impact on the domestic economics of the population in Northwest Mexico, particularly so in the main cities of Sonora State where low-income households face financial problems or must accept uncomfortable living conditions. Programs from the Mexican Government have targeted the reduction of building services operating costs, but these tend to focus on the replacement of old appliances rather than modifying construction techniques.

The challenge is to find design strategies that improve the passive cooling abilities of dwellings, reducing the need for air conditioning, and that are also acceptable to the house builders; this is a consideration of material availability, skill demanded, and additional cost. This research uses thermal simulation to investigate the effect of construction materials and building form on thermal comfort on the Sonoran climate. Whilst these issues have been widely discussed in the literature, there is little, if any, application to the extreme Sonoran climate and construction methodologies.

CLIMATE AND POPULATION

Sonora State, located in the Northwest region of Mexico (Figure 1). Arid and semi-arid conditions predominate in this region and the Mexican National Weather Service has recorded temperatures of up to 47 ºC in several cities of Sonora State [1].

Figure 1. Location of Sonora in Mexico [2].

There are three major climatic zones within Sonora, as defined by the Köppen Climate Classification and Universal Thermal Scale [3]. Climate is determined by altitude rather by latitude with the regions of higher altitude tending to be cooler. These regions are BWh (very hot, dry, desert), BSh (very hot, dry, steppe) and CWa (hot, humid, subtropical) as shown in Figure 2.

Cities located in the desert and steppe areas experience mean summer temperatures over 30 ºC: the average maximum is over 36 ºC in desert, and over 32 ºC in steppe climates [4,5]. In the mountain regions temperatures can be much cooler, to the point at which snow is present every winter.

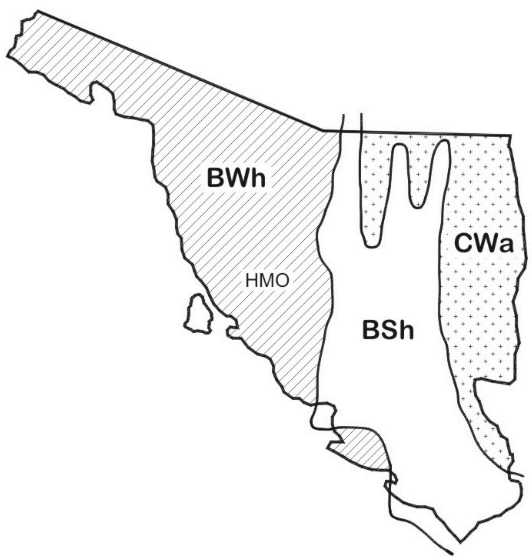

Figure 2. Prevailing climates in Sonora. Note: HMO - Hermosillo City.

The major cities of Sonora were founded in lower, flatter lands (the plains), and therefore most of population resides in the hotter areas. Figure 3 shows the estimated population living in each of the climatic zones; this was determined by matching data from the 2005 official census [6] with the geographical boundaries suggested by Figure 2. The vast majority of the population live in the desert hot-dry and steppe hot-dry regions.

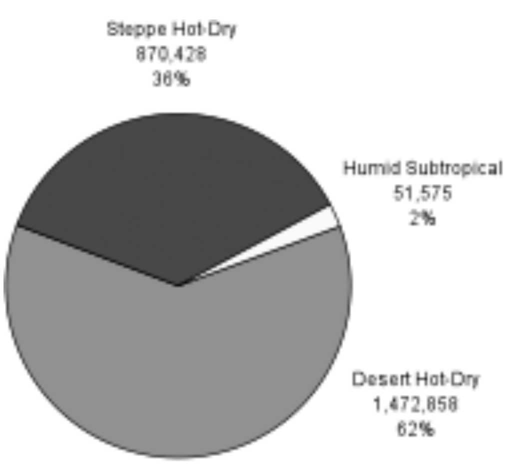

Figure 3. Population distribution in Sonora according to climatic zones.

Table 1 shows a profile of the main climatic features of Hermosillo City: lowest (Min), mean (Ave) and highest (Max) average monthly temperatures; dew point temperature (DP) and relative humidity (RH). According to the Universal Thermal Scale [3], when classified by its mean year temperature, Sonora is a “hot zone”.

Table 1: Monthly temperature profile and relative humidity (10-year average) in Hermosillo (29º15'N, 110º59' W) [5].

Month	Temperature				RH
	Min	Ave	Max	DP	%
Jan	6.9	15.7	24.6	9.2	68
Feb	8.4	17.2	25.3	9.1	62
Mar	10.0	19.3	27.8	10.3	58
Apr	12.7	22.4	30.7	13.2	59
May	16.4	25.8	34.0	16.3	58
Jun	21.9	30.8	37.9	21.7	62
Jul	26.0	32.8	38.5	24.7	64
Aug	25.5	31.9	37.5	24.6	67
Sep	24.0	30.9	36.6	24.4	71
Oct	18.2	26.1	33.6	19.6	69
Nov	11.3	19.9	27.5	13.5	69
Dec	7.9	16.2	24.2	10.1	69
Year	15.8	24.1	31.5	16.4	65

EXPENDITURE ON ELECTRICITY

High temperatures in most cities in Northwest Mexico compel the occupants to install mechanical cooling systems. The compressors and fan motors of these cooling systems consume electricity. Due to poor design of dwellings, such consumption is higher than it needs to be: due to relatively low salaries this electricity demands an excessive proportion of the householders’ income.

Table 2 shows the annual electricity consumption for a *middle interest* house (see below for definition of dwelling types). This profile was estimated by taking the mean monthly metered consumption over a two-year period for twenty middle interest houses in Hermosillo, Sonora. The average consumption for December to March was assumed to represent the base load, which was subtracted from the consumption recorded in April to November to estimate the consumption due to air conditioning in these months. This value is shown in the third column of Table 2. It is thus estimated that approximately 53% of the electricity annually consumed by a dwelling is due to air conditioning.

Electricity is expensive in Mexico. It is avoided where possible - cooking appliances and water heating tend to use gas. Typically, electricity is used for air conditioning, refrigeration, the washing machine, lighting, ceiling fans and the television. The typical cost of electricity is 1.05 pesos per kWh in winter and 1.44 pesos in summer, approximately £0.05 and £0.07 per kWh respectively. During summer season (May 1st to October 31st) a subsidy is applied to domestic tariffs, whereby the federal government makes a contribution towards a reduction in the unit price, according to the consumption rate, which is reflected as a discount on electricity bills.

Table 2. Relationship between total electricity consumptions and electricity used by air conditioning (A/C) in a typical middle interest house.

Month	Total Consumption **kWh**	Estimated consumption of A/C **kWh**	Proportion Attributed to A/C **%**
JAN	406	0	0.0
FEB	415	0	0.0
MAR	442	0	0.0
APR	646	0	0.0
MAY	863	364	42.2
JUN	1,450	950	65.6
JUL	2,121	1,622	76.5
AUG	2,257	1,757	77.9
SEP	1,915	1,416	73.9
OCT	1,134	635	56.0
NOV	675	0	0.0
DEC	413	0	0.0
YEAR	**12,737**	**6,744**	**53.0**

The average monthly income of a typical family living in a middle interest house is 9,900 pesos (approximately £483); the Mexican minimum wage is just 6% of that in UK [7, 8]. Hence, whilst the unit cost of electricity is similar to that in the UK, household incomes are lower, and thus householders must devote a larger proportion of their income to paying for electricity.

MODERN RESIDENTIAL BUILDINGS

Whilst this research focuses on residential buildings, in which the predicament of low income and fuel poverty is more prevalent, the problems of using air conditioning apply also to non-residential buildings.

There are three categories of dwelling in Sonora: social interest, middle interest and high residential. The social interest dwelling has the smallest floor area (figure 4) and the high residential dwelling has the largest one. These floor areas are related to the cost of the houses and thus approximately to the economic status of the occupant. For example, *vivienda de interés medio* (middle interest) describes a type of housing and this tends to be occupied by middle-income or middle-class families. All social interest dwellings, and most middle interest dwellings, are built in mass production. To reduce costs, mass house builders tend to use a common plan for all houses, changing only the façades (Figure 5). One common feature is that dwellings are arbitrarily orientated according to the street layout with no consideration given to thermal effects of orientation. Developers tend to use as few materials as possible, reducing building mass, thermal insulation and other important features critical in passive design [9] and will fit in as many plots as possible in a given site.

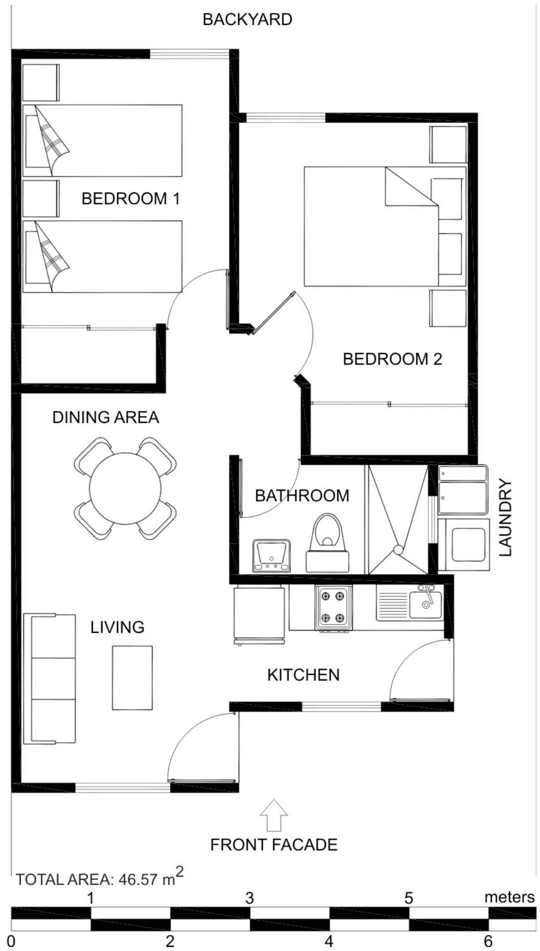

Figure 4. Typical floor plan of social interest housing.

Traditional construction materials included mud adobe bricks, offering walls of a high thermal mass. Roofs were made of dry red-grass or palm leaves over beams laid upon the walls, covered with compacted earth and a layer of resistant material, such as rendered brick. Nowadays, these techniques have fallen into disuse [10].

For modern housing, the most common modern construction material for walls is the hollow concrete block which has poor thermal and acoustic qualities. Roofs are typically concrete with a layer of polystyrene thermal insulation (Figure 6), this having a lower thermal mass than the traditional construction.

Figure 5. Typical façade of social interest housing.

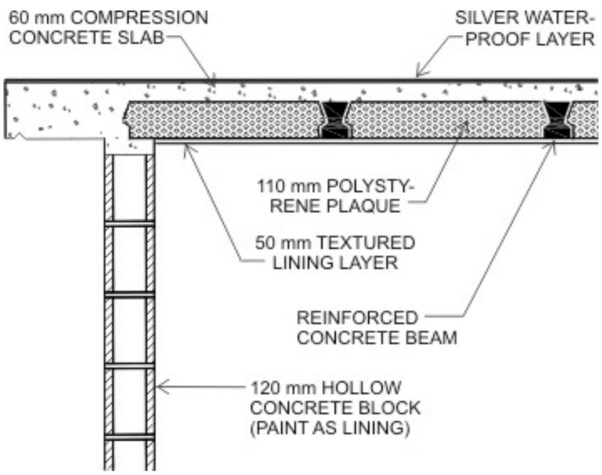

Figure 6. Typical detail of social interest housing.

The envelope of social interest housing is clearly not suitable for the climate. There are thermal bridges through the insulation layer, little thermal mass, the walls lack protection against solar radiation, and windows are single glazed with an aluminum frame. The waterproof membrane on the roof is always asphalt with an outer layer of aluminum paint to reflect sunlight. On-site measurements show that its reflection of approximately 35% tends to fade with time.

THERMAL ANALYSIS

Thermal analysis of the three housing types is being carried out using Ecotect. The thermal performance of base cases has been tested against on-site measurements to validate the data [11]. The variables being explored include wall and roof construction (thermal mass and thermal insulation), fenestration strategy and orientation. The aim is to identify which passive design techniques best match the climate of Sonora toward reducing, or preferably eliminating, the need for air conditioning. Consideration is also given to incorporation of these methods within local construction practice, and thus life-cycle costing will be used to evaluate affordability, the key to acceptance of these ideas.

Figures 7 to 12 show the thermal performance of the house shown in figure 4, which represents the type known as Social Interest housing. These results are for the Living area and Bedroom 1, for three months (May, July and September), and for two orientations (the front façade of the building facing either North or East).

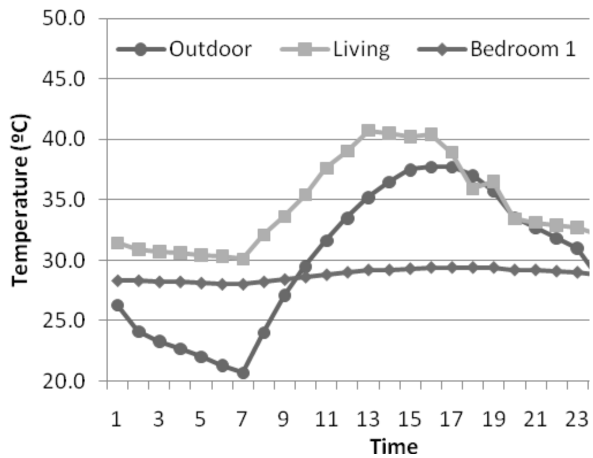

Figure 7. Hourly temperature profile for a typical Social Interest dwelling. Date: May 21st. Front of house faces North.

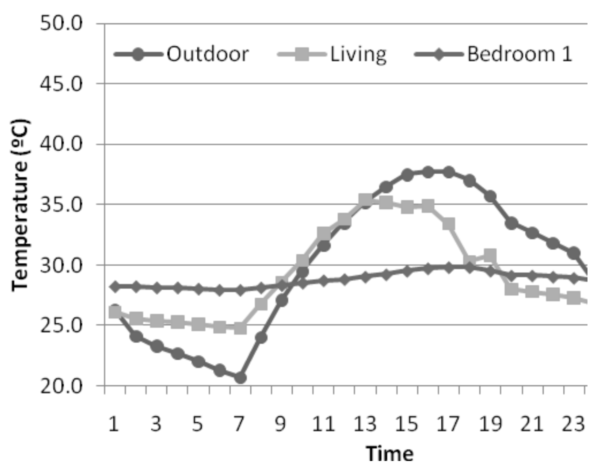

Figure 8. Hourly temperature profile for a typical Social Interest dwelling. Date: May 21st. Front of house faces East.

It can be seen that Ecotect predicts that the interior temperature sometimes exceeds outdoor temperature, as a result of high heat capacity of materials used in modern housing buildings. This is confirmed by personal experience, such as the tradition of sleeping outside at nighttime in summer because this is cooler than inside free running houses.

Figures 7 to 12 show that when the living room is north-facing it tends to be hotter than outdoor temperatures across the whole day; when the living room is east-facing, it is cooler than outdoors in the afternoon. The bedroom, which is south and west facing in these examples, tends to remain at a relatively constant temperature.

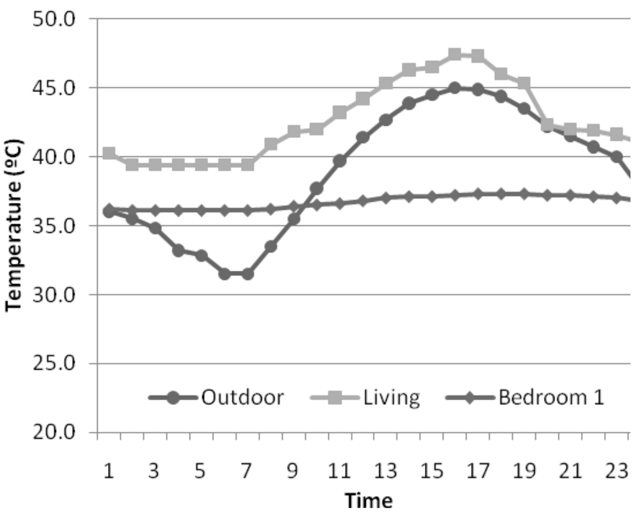

Figure 9. Hourly temperature profile for a typical Social Interest dwelling. Date: July 21st. Front of house faces North.

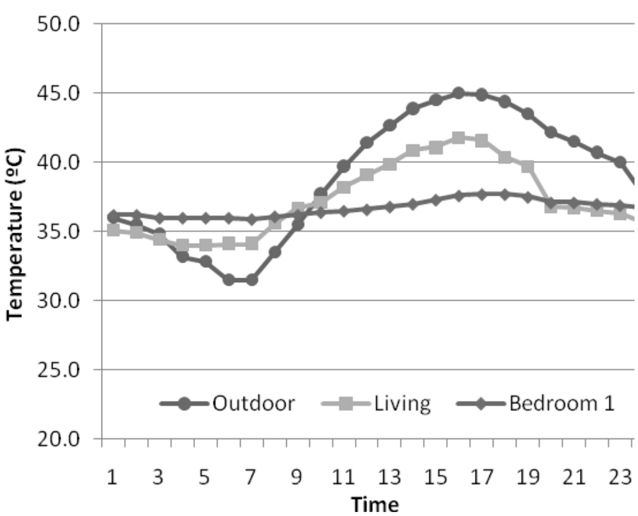

Figure 10. Hourly temperature profile for a typical Social Interest dwelling. Date: July 21st. Front of house faces East.

Whilst effects of orientation are reasonably well known, there are concurrent cultural issues; for example, it is not acceptable for private zones such as bedrooms to face the road. Despite the large effects of orientation, shown here as the differences between the Living room and Bedroom in Figures 7 to 12, cultural consideration means that passive design by orientation may not be an acceptable solution. Furthermore, natural ventilation via openable windows is impractical in this region because of the dust content of outdoor air. Dwellings are usually mechanically ventilated through the air conditioning system and this device incorporates air filtration; the objective of this research is to remove the need for the mechanical cooling part of such mechanical ventilation devices. Therefore, this research focuses primarily on façade design – window design, solar shading, and thermal response of the fabric.

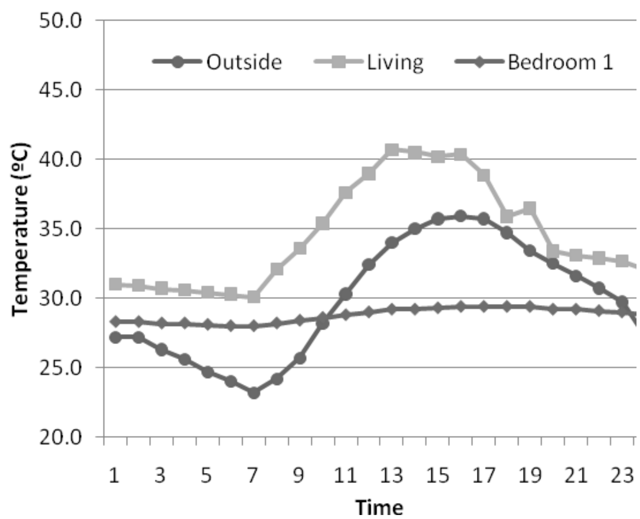

Figure 11. Hourly temperature profile for a typical Social Interest dwelling. Date: September 21st. Front of house faces North.

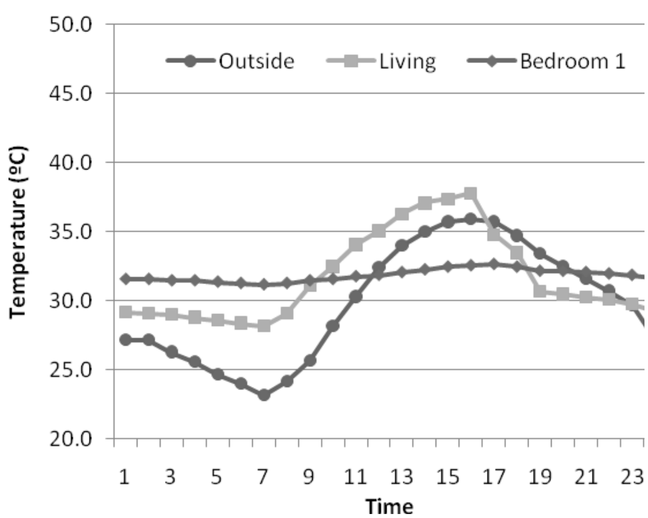

Figure 12. Hourly temperature profile for a typical Social Interest dwelling. Date: September 21st. Front of house faces East.

There have been several studies focused on passive design techniques in climates similar to Sonora. Those carried out in Arizona, USA [12-14] present similar climatic conditions but are applied to different styles of dwelling and face different economic problems. In the case of Mexico's hot-dry climate, the problem gets worse as it applies to lower socioeconomic conditions of population.

Thermal comfort for people in Sonora is found between 22 and 27ºC and between 40 and 70% relative humidity [23]. Ecotect analysis suggests that these conditions are exceeded for at least six months of the year in the absence of mechanical air conditioning.

Initial analyses suggest that addition of some simple features such as shading, fenestration and orientation, leads to reductions in thermal loads up to 35 percent. This means that small changes in construction practice may improve thermal design with no major impact on budget.

CONCLUSION

Most parts of Sonora, as well as other states in Northwest Mexico, exist in a desert environment. For summer months it is necessary to install evaporative coolers or air conditioning and these consume significant amounts of electricity.

Desert cities in Mexico are characterized by extreme climatic conditions, aridity and high temperatures. Modern dwellings tend to ignore principles of passive design, and the resulting poor thermal response leads to economic problems, particularly for families living in social interest houses.

Thermal simulation is being used to identify passive design techniques that may be successful in minimizing or eliminating the need for air conditioning. Cost-benefit analysis will also be used to determine those techniques that are most likely to be adopted by architects and house builders.

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