Thermal Comfort and Energy Performance of Social Housing in Hot-Dry Climates

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ABSTRACT: In Mexico during the last decade, the government has supported programs to develop social housing in order to assist low-income families. This type of initiatives has allowed low-income families to own a place to live, but it has also promoted the spread of housing developments with house models of similar characteristics in the very diverse geographical and climatic zones of Mexico.

Even though some of the dwellings have few differences depending on the region they belong to, they do not reflect climatic adaptations to the regions where are located. It is common to find similar dwelling designs in contrasting climates, such as hot humid or cold-temperate, with few differences in their architectural program, ornament and finishes; even the construction systems tend to be very similar among them.

This situation could cause deficiencies and improper functioning of the dwellings, basically related to lack of thermal comfort and high-energy consumption, leading to social and economical problems as a consequence.

The diagnosis of current conditions of representative social housing in hot-dry climate has been performed, through monitoring and simulation of thermal behaviour of a house model in hot and cool seasons. To evaluate the performance of housing, the calculations of various indexes that involve thermal performance, energy consumption and thermal comfort were calculated, for example decrement factor, lag time and thermal comfort sensation. Finally, recommendations to improve the habitability and energy efficiency of houses have been proposed.

INTRODUCTION

During the last decade, housing construction in Mexico has increased dramatically, despite the economic and financial crises, and is one of the main drivers of the Mexican economy. Approximately 35% of homes are built for low-income families (called "social housing") and funded by the Institute of Housing Fund for Workers (INFONAVIT for its acronym in Spanish).

According to INFONAVIT’s definition of “social housing”, it refers to a dwelling with an economic value is of $17,560.00 USD (price in January 2012). This type of social housing initiatives has allowed low-income families to own a place to live, but it has also promoted the spread of housing developments with similar characteristics in the very diverse geographical and climatic zones of Mexico.

These dwellings have few differences even though they are built in different climatic zones. It is common to find similar dwelling designs in contrasting climates, such as hot humid or cold-temperate, with few differences in their architectural program, ornament and finishes; even the construction systems tend to be very similar among them.

This situation can cause deficiencies and improper functioning of the dwellings, basically related to lack of thermal comfort and high-energy consumption, and potential social and economical problems to the users, as a consequence. This situation is particularly relevant in areas with hot dry and hot humid climates, which represent around 70% of the Mexican territory.

This article presents the evaluation of a representative model of social housing, built in Hermosillo city (Northwest Mexico) between 2009 and 2011 [1]. The diagnosis of current conditions has been performed, through monitoring the indoor temperature.

To evaluate the performance of the case study, calculations of various indexes that involve thermal, energy and environmental comfort performance, were calculated: for example, decrement factor (DF), lag time (LT), adaptative thermal comfort sensation and air conditioning cooling load.

To improve the habitability of housings, proposals of some building envelope systems were analyzed through thermal simulations, which were performed using the Design Builder software [2].

LOCATION AND CLIMATE

Hermosillo city is the capital of the state of Sonora. It is located in the north-western zone of Mexico, 275 km South of the U.S. border and 2,037 km from Mexico City, at 29° 05' North latitude.

High solar radiation levels, clear skies and daily and annual high temperature swings, are typical of the local climate.

The maximum air temperature exceeds 38 °C on an average of 90 days of the year, including most days from early June until early September, with minimum air temperatures of 20-25°C and maximum about 40-44°C. Air temperatures can reach in extreme cases up to 50°C . Average relative humidity oscillates between 50 and 15%; however, the arrival of moisture air in August makes it feel a little bit humid (figure 1).

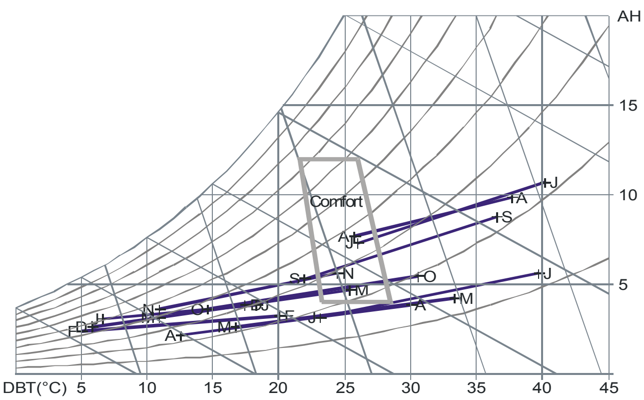

Figure 1. Maximum and minimum monthly average temperature and relative humidity of the site, plotted on the psychrometric chart. [3]

The warm season extends for 5 or 6 months per year, and the use of air-conditioning is necessary inside buildings during this period. Ground surface temperatures may reach up to 70°C when exposed to solar radiation.

Winters are comfortable, with minimum temperatures of 0-7°C and maximum between 25 and 30°C. The city has almost 300 sunny days per year; in spring and summer, solar radiation can rise up to 1000 W/m^2. The rainfall is scarce; with an annual total precipitation of 225 mm. August is the wettest month of the year (27 mm). Rain is particularly scarce from April through June. Although thunderstorms occur occasionally during every month of the year, they are more common during the rain season, which happens from July to mid-September, when humid air comes in from the Gulf of California. These can bring strong winds. Winter storms moving inland from the Pacific Ocean occasionally produce significant rains but are not frequent.

Despite the harsh environmental conditions, the new areas of the city are neither planned well nor prepared for hot-dry desert climate. This situation contrasts with the historic old town, which is conformed by narrow streets, plenty of adobe houses with small windows, vegetated central patios, arcades and light colours.

Recently developed districts have wide streets, large paved areas, and detached buildings. New housing developments, even economic or high-income houses are designed with the same criteria for mild climate of central regions of Mexico; as a consequence, there are huge energy consumptions during the warm period.

Local people have adapted their lifestyles to their circumstances, and it is common that necessary physical activities and movements, such as walking, are reduced to the minimum and preferably realized during night or early morning hours. During the summer months, people often wear long-sleeved thick shirts, cotton underwear, hat and boots as radiation and heat shields. However, the city inhabitants enjoy open-air activities, social and family gatherings are made outdoors the whole year. In spite of this, most of the available outdoor spaces are improvised with poor comfort conditions.

A field study [4] showed that even when most of the population is quite dependent on air conditioning systems, there is a certain level of seasonal acclimatization. We found that the average outdoor temperature in the shadow that people have voted as comfortable for spring was of 28.7°C and for summer of 36.2°C. The dry air makes the hot temperatures more tolerable early in the summer season.

During spring, better comfort sensations are registered due to higher wind speeds; while during summer the wind is usually very hot and dusty, so it cannot be used to improve thermal comfort through passive cooling.

Considering the extreme climate conditions, architectural design criteria must be adapted and applied stringently in order to minimize the negative climate effects on the dwelling occupants and their energy consumption.

CASE STUDY DESCRIPTION

A house model, representative of social housing built in Hermosillo city between 2009 and 2011 [1], was selected as case study, and has been called HMO1 (the actual name of the model and company has been omitted due to a confidentiality agreement with the development companies).

HMO1 house has a construction area of 38.71 m^2 and is built on a 117 m^2 lot. The Unit has two bedrooms, a living-dining area, a kitchen and a bathroom. It includes a one-car parking area, service patio and garden (figure 3).

A North-South orientation of the main elevation prevails in most units of this kind (figure 2). Walls are made of concrete hollow blocks and the roof is a pre-cast beam and polystyrene panels system without any additional insulation. None of the openings has any kind of solar protection or shading device. Regarding the exterior areas, in most cases the house does not have any paving material and it does not have any shading devices. In rare cases the inhabitants have modified these conditions, mainly because of economic restrictions.

Due to climatic conditions, most users utilize some kind of air conditioning system to ensure their comfort. The most commonly found is an evaporative cooler system, known locally as “cooler”. This system is preferred over other air conditioning systems due to its cost efficiency: compared to an A/C unit, the “cooler” costs less and is mechanically simple to repair and maintain. Some disadvantages are that it requires the use of water to operate and do not work very well in very hot climates over 40ºC. In addition, when highest temperatures occur, relative humidity increases because of the raining season, decreasing the cooling effect.

Figure 2: Main façade (South) of HMO1 house, a representative model of social housing in Hermosillo, Sonora.

There are also individual air conditioning systems that are installed in a window or wall opening, as well as split type systems. These are usually located in the bedrooms, complemented by a regular fan, commonly found at the living-dining area.

MONITORING PROTOCOL

The diagnosis of the current conditions has been performed, through monitoring and simulation of thermal response to the climatic conditions in hot and temperate representative months.

The monitoring of temperature and relative humidity inside the house was made according to ISO-7726: 1998 [5]. We installed a temperature and relative humidity sensor in each room of the house, suspended at 1.20 m above the ground in the centre of the room. Measurements have been performed by HOBO data loggers with accuracy of ± 0.5 ° C in temperature and ± 5% in relative humidity. The measurement interval was set every 10 minutes.

Simultaneously outdoor climatic data was obtained from a weather station located on the roof of the School of Architecture at 4 km away from the house, with an altitude difference of less than 50 meters. Station’s data were also used in simulations.

Seven months were monitored, between in May and October 2011, because this is the hottest season of the year and thus the most critical when addressing comfort conditions within buildings.

SIMULATION PROTOCOL

In order to analyse the new wall materials proposed for the current house model, a simulation of the energy and thermal performance was done, using the software Design Builder V. 3 [2]. This software was selected because it provides a better flexibility when analysing different aspects of the dwelling, and due to the research team’s previous experience with it.

Two simulation series were carried out: in the first one, the dwelling was analysed using natural ventilation (as measured) in order to define the relation that the building has with the environment. In the second one, the simulation included the use of active cooling systems in order to know the energy consumption caused by the air conditioning equipment.

Simulations were performed for the entire year, however for more clarity results are shown only for July and October as the hottest and coolest month within the monitored period.

There were analysed four types of wall materials; one of them is the concrete hollow block (**MHB**), which is the original material of the measured house and most prevalent in social housing in the region. Three more materials were selected: adobe (**AD**), red brick (**RB**) and lightweight concrete blocks (**LWC**). Their thermal properties are shown in table 1.

Wall finishes and colours are considered the same as those of the monitored house, as well as the roof constructive system (precast concrete beam and polystyrene panels).

Table 1: Wall building material properties proposed for simulation

Material	**AD**	**RD**	**LWC**
Conductivity (W/m C°)	0.95	0.87	0.11
Specific heat (J/Kg C°)	920	1330	896
Density (Kg/m3)	1600	1800	550

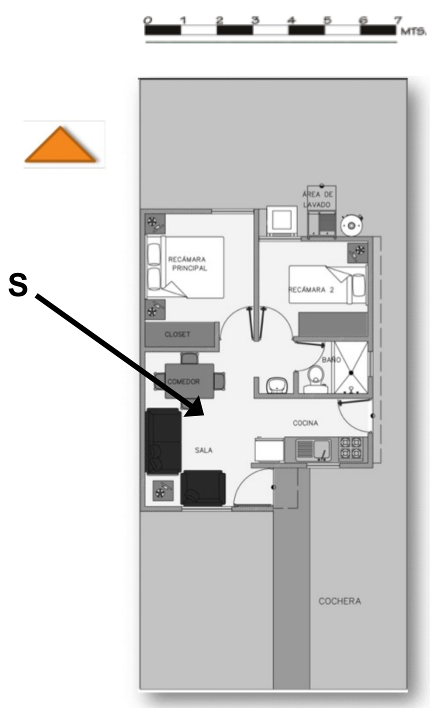

Figure 3: Plan of HMO1 house model. Location one of temperature and humidity sensor (S) is indicated.

FREE RUNNING PERFORMANCE ANALYSIS

To evaluate the thermal performance, the energy required for acclimatization, and the environmental comfort, four parameters have been used: Decrement Factor (DF), Lag Time (LT), hours of discomfort (HD) and cooling energy load (Q).

For buildings without air conditioning are important the decrement factor (DF) and the lag time (LT), as they involve the effect of all thermo-physical properties of building materials. Barrios et al. [6] have defined these parameters as follows:

The decrement factor is defined by:

$$DF = (Tinmax - Tinmin)/(Textmax - Textmin) \qquad (1)$$

Where: Tinmax and Tinmin are the maximum and minimum indoor air temperatures, respectively, and Textmax and Textmin are the maximum and minimum outdoor temperatures, respectively.

The lag time is defined as:

$$LT = t(Tinmax) - t(Textmax) \qquad (2)$$

where t(Tinmax) and t(Textmax) are the times of day when the indoor air and outdoor air temperatures reach their maximum value, respectively.

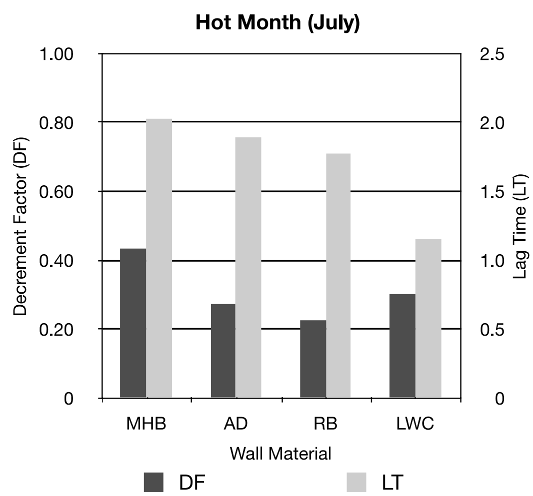

Figure 4: DF and LT calculated for July.

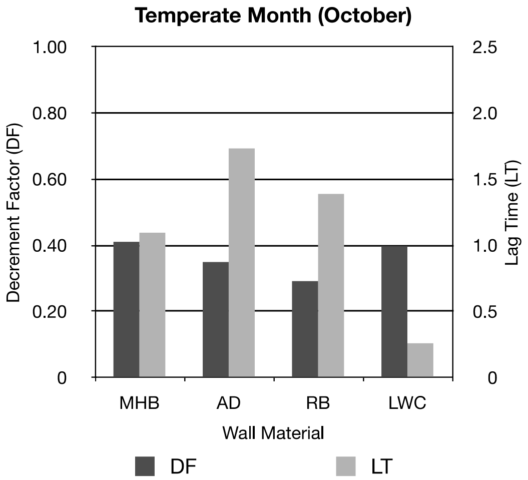

Figure 5: DF and LT calculated for October.

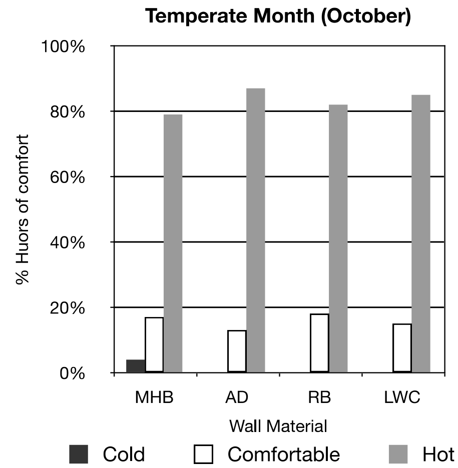

Figure 6: Percentage of time during the temperate month (October) when temperatures fall within the warm, cold and comfort zone.

In hot dry climates, the smaller the decrement factor (DF), the better the thermal performance. In general, the larger the lag time (LT), the better the thermal performance. In Figures 4 and 5 the calculations of the DF and LT for the months of July and October are plotted. As shown in the graphs, the materials with the best performance considering both periods would be RB and AD, according to the criteria mentioned in reference [6].

After analyzing different models of comfort evaluation, the adaptive model of neutral temperature proposed by R. De Dear et. al. [7] was selected for this study. This model is represented in equation (3):

$$Tn = 17.8 + 0.31\ (To) \qquad (3)$$

Where: Tn = neutral temperature and To = average monthly outdoor air temperature in Celsius degrees.

Neutral temperatures were defined for July and October (table 3) and the limits of the comfort zone were fixed as Tn ± 2 ºC, acceptable for acclimated people. The graph of Figure 6 shows no significant differences between the proposed and original material, since the percentage of hours of discomfort is around 80% (warm) and the percentage of comfort hours, fewer than 20%. The graph of July was omitted, since in all cases showed 100% warm discomfort hours. Results confirm that even for the less warm month of the season, it is recommended the use of air conditioning.

Table 3: To and Tn Temperatures (ºC) for temperate and hot-dry months, using the Brager & De Dear formula [7].

Month	To (ºC)	Tn (ºC)
Hot Dry (July)	25.53	25.72
Temperate (October)	32.43	27.85

ENERGY ANALYSIS

The thermal cooling load calculation for all materials was performed considering the same occupation schedule. For all calculations it was considered that dwellings are closed and unoccupied.

Since we have not measured the actual consumption in the house HMO1, because it is a new no furnished unit, this was calculated using the same parameters as with the other materials. The purpose was to compare only the building envelope's performance in all cases.

The air conditioning system for all cases is a split type equipment with an efficiency EER of 10 and COP of 2.64, the unit has 2 tons of refrigeration.

To compare energy demand, in Figure 7 the consumption of two months for each material is plotted. As can be seen, it is clear that the best material to be used with air conditioning is the lightweight concrete block (LWC), despite having the lowest LT of all materials.

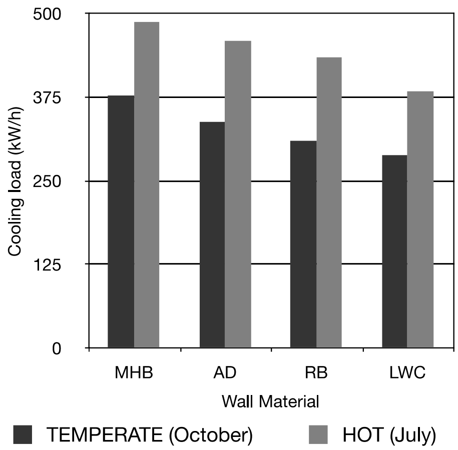

Figure 7: Monthly thermal cooling loads for original and proposed materials for October and July.

CONCLUSION

This study presents a comparative analysis of the thermal performance of different building materials used in exterior walls of social housing. The comparison was made between the actual temperature monitored inside the home (constructed with concrete hollow blocks, MHB) and computer simulations where walls are substituted with other building materials, frequently used in the region, such as adobe (AD), red brick (RB) and light weight concrete blocks (LWC).

This analysis suggests that the material with the best thermal performance are the LWC, because of its lower energy consumption for air conditioning, and RB that has the lowest DF and high LT for no air conditioning situation.

This is an important result because, as seen in the comfort analysis, during 6 months of the year passive systems are enough to find comfort conditions, but the rest of the time it is necessary the use of active cooling systems, representing an additional cost to low-income families, that frequently live in this type of house.

For an adequate housing thermal behaviour in different climate situations, the combination of materials can be favourable. For example, using RB with external insulation, or LWC on surfaces of high uptake of energy. However, the cost of the insulation materials are high in Mexico, thus should make a detailed cost analysis to make a decision.

More than 1.2 million dwelling units were built in Mexico during 2008 and 2009. It is expected that at least 800,000 units will be built until 2013, 36% of those are social – economic houses. Under the current conditions, these numbers represent a vast amount of dwellings which will not meet minimum requirements for thermal comfort and energy efficiency, and which could cause extensive energy consumption and infrastructure investment, as well as permanent environmental damage.

The study shows that the social housing model considered is inadequate to most hot-wet and dry climate regions in Mexico, inevitably leading to the use of air conditioning five to six months a year, due to poor site analysis and bioclimatic design strategies. Therefore an in-depth review of actual model's design is urgent and necessary, based on rigorous technical analysis of the climatic conditions of the site and thermal and energy performance of the proposed models.

It is also necessary to make a socio-economic study that considers not only the initial space requirements of the inhabitants, but also the use of housing over time, including the costs of operation and maintenance at acceptable comfort conditions.

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