Cost benefit energy analysis of the building envelope systems with Ener-Habitat

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Abstract

During the last decade, housing construction in Mexico has increased dramatically, despite the economic and financial crises, it is one of the main drivers of the Mexican economy; the government has supported programs to develop social housing in order to assist low-income families. This type of initiatives has allowed low-income people 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. The correct selection of the envelope materials is one of the first and most effective passive strategy that must be considered in the design of a housing. However, just selecting the materials by knowing their thermal properties is not enough to make an appropriate decision about the construction system. For this reason, we need a tool like Ener-Habitat, which allows a quick assessment of thermal and energy performance of a building system consisting of several layers, through the time-dependent calculation of heat transfer, suitable for high thermal mass materials, such as those generally used in Mexico and the climates of Mexico with high solar radiation and large temperature swing during the day. The study proposes a method to analyze the cost and energy benefit of building systems, and as example analyzes some walls building systems, in a hot-dry climate city of Mexico, during the air conditioning season. This tool allows, at early stages of architectural design, quick assessments for decision taking on the building systems choice, in relation with better energy performance. Ener-Habitat was created by researchers from six academic institutions in Mexico and was funded by the National Council for Science and Technology and the Ministry of Energy of Mexico.

Keywords: design tool, ener habitat, heat transfer, passive systems, building envelope, energy performance

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1. Introduction

Mexico, as an emerging country, has experienced rapid economic and population growth. Although this rate has declined in recent years, has influenced the growth of cities and therefore the growth of its building stock, including housing type buildings being those who observe the highest growth.

On the other hand, over 70% of the country has warm climate, either dry or wet, and these regions have experienced the most rapid development, which is good, however the growth has been so little regulated and homes do not have regional adaptation strategies to local climate.

There are some schemes of federal support and subventions for green or sustainable housing. The "Green Mortgage" from INFONAVIT [1] (Institute of the National Housing Fund for Workers, for its acronym in Spanish), is mainly aimed at the incorporation of some systems called "eco-technologies" that allow some resources savings, like water or gas, or insulating materials that aim to reduce electricity consumption by air conditioning or heating.

This has led to housing developers to incorporate the "eco-technologies" as a "recipe", by selecting them from the official catalog, and using them only as accessories and not integrated as part of the design of the building.

These dwellings have only 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 the lack of thermal comfort, high-energy consumption, and potential social and economical problems to the users, as a consequence.

2. What is Ener-Habitat?

Ener-Habitat is a tool for design and evaluation of building systems in building’s envelope (walls and roofs). It was developed to evaluate the thermal performance of the constructive systems of the envelope of a building for the climates of México’s main cities. It solves the time dependent heat transfer equation in one or two dimensions, considering periodic outdoor temperature, solar radiation. All the needed data is introduced through a Graphical User Interface.

It is particularly suitable to estimate the thermal loads in climates where there is a large temperature swing during the day, for massive building envelopes, which are typical in Mexico and where air conditioning or heating technologies are not available all year long, either because it is not necessary or because there are no economic possibilities to invest in a mechanical equipment. In these cases is important to have well designed passive systems.

The user requires knowing the orientation and slope of outdoor surface (wall or roof), layer’s thickness, and material’s thermal properties such as conductivity, density and specific heat, as well as solar absorance of the outdoor surface. It is a free access cloud-computing tool, available previous registration through a website [2].

3. Methodology and case study

In this study we evaluate different wall constructive systems, and we compare their cost per square meter with their thermal performance during the warm season in a hot-dry climate city.

Since Ener-Habitat calculates the heat transfer only in a square meter of wall, it is not possible to make a full cost-benefit analysis. Considering this, we propose a way to compare the relation cost-cooling load,
among a group of building systems and determine which is the most convenient, that is, which has a combination of the lowest cost and lowest thermal load.

3.1. Case study

Hermosillo city, capital of the state of Sonora in Mexico, has been selected as an example of hot-dry climate location with high solar radiation and large temperature swing during the day, and it has participated in the initial field study of Ener-Habitat. 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. The warm season extends for 5 or 6 months per year, and the use of air-conditioning is necessary inside buildings during this period (May to October).

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/m². 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.

A field study [3] 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 temperature that people has voted as comfortable was 26.9 °C in winter and 32.2 °C in summer (± 2.45 °C). The dry air makes the hot temperatures more tolerable early in the summer season.

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.

3.2. Methodology

For the analysis, we have selected two of the most used materials used in the region for wall housing construction, which are hollow concrete block (HB) and red brick (RB) [4], and also stabilized adobe (AD) and autoclaved aerated concrete (AAC) were added as an innovative option in this context. We have considered the same finishes for all systems, both inside (layer plaster and latex paint 1.5 cm) and outside (cement and sand mortar of 1.5 cm thick with white paint finish). For all a 0.3 solar absorptance was considered. The simulations to obtain the cooling load were done on a Wall oriented to the east. Ranking results will be the same independently of the wall orientation.

A total of four systems were simulated and a variation for each one. For the first three materials (HB, RB and AD) the variation consisted of placing a 4 cm thick insulating layer of expanded polystyrene on the outer face (iHB, iRB and iAD) and the variation for AAC was to keep the material only with a white paint layer for finish protection, i.e. without inside and outside mortar (sAAC). Table 1 presents the thermal properties of the main materials of the analyzed construction systems.
In order to compare the different building systems, the total cooling load for air conditioning (Q) has been calculated with Ener-Habitat for warm season, that covers May to October. The unit cost per square meter (C) of each construction system has been also calculated.

This was followed by the normalization of results, with reference to the maximum (Q_max) and minimum (Q_min) cooling loads and maximum (C_max) and minimum (C_min) cost per square meter of the group of materials to be analyzed. Equations 1 and 2 show how the normalized cooling load (Q_norm) and the normalized cost (C_norm) of each material were obtained.

\[
Q_{\text{norm}} = \frac{Q_{\text{max}} - Q}{Q_{\text{max}} - Q_{\text{min}}}
\]  
\[
C_{\text{norm}} = \frac{C_{\text{max}} - C}{C_{\text{max}} - C_{\text{min}}}
\]

Finally, \(Q_{\text{norm}}\) and \(C_{\text{norm}}\) of each construction system were added to obtain the ranking value, as shown in Table 2. The higher the ranking of a system, the better its cost-benefit. In bold are indicated the ranking of the materials considered as best and worst. Cost is expressed in Mexican pesos per square meter by November 2012.

Table 2. Analysis of building systems based on cost and cooling load

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W/m K)</th>
<th>Density (kg/m³)</th>
<th>Specific heat (J/kg K)</th>
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<tbody>
<tr>
<td>Concrete of hollow block (HB)</td>
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<tr>
<td>Red Bick (RB)</td>
<td>0.7</td>
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<td>800</td>
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<tr>
<td>Stabilized adobe (AD)</td>
<td>0.58</td>
<td>1500</td>
<td>1480</td>
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<td>Autoclaved aerated concrete</td>
<td>0.12</td>
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4. Results discussion

As seen in Fig. 1, the stabilized adobe (AD) was ranked, as the worst material, due to the combination of cost and energy consumption, however is neither the most expensive nor the greatest energy consumer. The hollow concrete block (HB) was found to be the highest consumer, but the low cost material makes him more popular within housing developers. The autoclaved aerated concrete (AAC) get also a not so good ranking, it has a good energy performance and its cost is very high.

The autoclaved aerated concrete (sAAC) without mortar finishes was the better qualified material, however, two good choices are the hollow concrete block and red brick with the insulating layer of expanded polystyrene on the outer face, iHB and iRB respectively, because they are good energy performing alternative and their costs are lower. These systems are well known by the builders and are produced in the region.

![Fig. 1. Ranking of building systems based on cost and thermal cooling load](image)

5. Conclusions

An analysis method has been proposed to assist in the selection of a construction system based on cost and the cooling load per unit area. Through this method it is possible to rate different systems in the design stage of a building, without having to conduct a cost-benefit analysis that involves the entire project of the building and a comprehensive thermal simulation.

The same methodology allows us to quickly compare indicators for non-air conditioned condition, such as the hours within the thermal comfort zone, the decrement factor or the time lag of each system and have more arguments for choosing the most suitable construction system.

However for the selection of materials is not enough to know only the cost or energy performance. It is also necessary to know other factors such as the proximity to the manufacturing site, the sustainability of the production process, and how much the builders and homeowners know them. Therefore an assessment of this type is required to be made in an interdisciplinary way, drawing on the expertise of the technicians.
in heat transfer or bioclimatic architecture, technicians on sustainability processes, and the empirical background of builders and housing developers.

Acknowledgements

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References