Comparative Analysis of the Thermal Behavior between Cellular Concrete Blocks and Stabilized Earth Blocks as Wall Materials

Marincic, I.*; Ochoa, J. M.; Alpuche, M. G.; González, I.

University of Sonora, Blvd. Encinas y Rosales, 83000 Hermosillo, Mexico

Abstract

In extreme climates like the desert climate of Northwest Mexico, indoor thermal conditions in buildings, and particularly in low-cost housing developments, are very uncomfortable. In buildings where the use of air conditioning devices can be afford, excessive energy is spent, leading to high acclimatization costs. In many cases, construction materials for low-cost houses are selected according to the lowest price, and not taking into account the best thermal behavior according to the local climate. Different types of blocks are widely used as a construction material for walls, such as earth blocks, adobe, concrete hollow blocks, cellular blocks, bricks, because of their low price and easy installation.

Design strategies must be very carefully selected according to the local climate, because they have a great impact on energy consumptions and in the quality of life of the occupants. The selection of the appropriate materials for the envelope is part of these design strategies, and is the main subject of this paper.

In this work we analyze the thermal behavior of a wall compound of two different materials: cellular concrete blocks and stabilized earth blocks. The monitored wall is part of a low-cost house constructed for demonstrative and experimental purposes. External and internal superficial temperatures have been measured and infrared images of the same areas have been analyzed.

Infrared thermography is particularly useful to evaluate non-homogeneous materials or non-traditional materials, from which not all thermal properties are known. The thermal behavior is analyzed, in relation to the expected characteristics according to the climate, such as adequate thermal insulation and thermal inertia of the envelope, which are different for air-conditioning and non air-conditioning situations.

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* Corresponding author. Tel.: +526622592179; fax: +526622592180.
E-mail address:imarincic@arq.uson.mx
1. Introduction

Low-cost houses, which are the highest number of buildings in many Mexican cities, are the response to the urgent necessity of accommodation for low-income families. This necessity must be satisfied quickly and with low costs, affordable for low-income people. The situation forces to housing developers to design and construct the dwellings with many limitations and, in many cases, the same house model is used in different climates [1], without regional and climate adaptations to the local conditions.

Blocks and bricks are construction elements very used in the region of Hermosillo city, Northwest Mexico, and surroundings, because of their quick installation, and, many of them, because of their low cost, which depends on the block material. In this work, we analyse the thermal behavior of a low-cost house envelope made of two different materials: cellular concrete blocks and stabilized earth blocks.

The case study analysed is an experimental house constructed in the university campus, which is representative of most of the low-cost local houses, regarding to construction area, shape, type of envelope and type of construction systems. The house design, however, apply passive thermal strategies according to the climate, in order to show other design and construction possibilities. The local climate is hot dry, with two representative seasons: hot dry and temperate. Temperature oscillations are high daily and along the year. Relative humidity is low and precipitations are scarce. Solar radiation levels are very high and skies are clear the most part of the year.

The study is carried out measuring superficial temperatures, using two methods: continuous sensors measures and instant infrared images. The aim is to know if the thermal behavior of the house materials is adequate for the hot dry local climate.

2. Methodology and case study

The method used in this work to analyze the envelope thermal behavior is to study the superficial temperatures evolution along time. Several weeks have been monitored and analyzed using two tools: superficial temperature sensors taking continuous measurements, and infrared images, acquired employing an infrared camera. To analyze the heat transfer through non-homogeneous materials or non-traditional materials from which not all thermal properties are known, is not easy. So, superficial temperatures at different hours and seasons can give information to know the thermal behavior of a building component made from such type of materials. With thermographic images it is possible to visualize in a false color scale (or gray scale) superficial temperatures, and analyze also the instant images as numeric values of superficial temperatures in a building component or specific material. Both measurement methods have been applied and compared. Also the advantages, disadvantages and convenience of both methods have been discussed.

The case study chosen for the analysis is an experimental and demonstrative house constructed in the university campus (Fig. 1) with 35 m² of construction area. A wall constructed part of cellular concrete blocks and part of stabilized earth blocks, with the same orientation, has been monitored. Both type of blocks are 15 cm thick. Exterior finishes are made of a cement and sand plaster, painted in a clear color. The interior side of the wall remains without finishes. The house is not occupied, so no lighting, electric equipment and occupancy loads are considered.

Continuous superficial temperatures have been taken with HOBO U10 Data Logger each 10 minutes. The sensors are located on internal and external sides of the wall, on both materials. Internal and external infrared images have been taken during several days in the morning and afternoon, in order to measure the periods of the day in which the heat fluxes have opposite directions. Images have been taken with a Fluke Ti25 camera [2]. In the camera’s configuration, the emissivity has been considered 0.95, because it is close to the most construction materials [3]. With the camera software, the images can be processed and
specific surface points can be selected and analyzed. Mean values of selected surfaces can be also obtained.

Fig. 1. Case study: experimental house.

In Mexico construction materials manufacturers usually do not specify thermal properties, and often they do not know them. So, for the selection of the most appropriate materials for the envelope, the most common method to obtain this data is to search in the bibliography the thermal properties reported for some similar materials. Another way is to test in a laboratory the real properties, which is less affordable. Monitoring the thermal behavior of a specific wall, or the interior space of a building, is useful to understand the thermal behavior of different materials, by analyzing their effects on indoor climate.

The most important thermal properties of the cellular concrete blocks and the stabilized earth blocks (Fig. 2), obtained from bibliography research, can be seen at Table 1.

**Table 1. Thermal properties of wall materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity ($W/mK$)</th>
<th>Density ($kg/m^3$)</th>
<th>Specific heat ($J/kg K$)</th>
<th>Diffusivity ($m^2/s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth block [6]</td>
<td>0.58</td>
<td>1500</td>
<td>1480</td>
<td>2.6 E-7</td>
</tr>
</tbody>
</table>
In hot dry climates, a combination of low thermal conductivity and high thermal mass is a good strategy for no air-conditioned building envelopes [7] [8]. In such climates, it is necessary to avoid as much as possible thermal loads during the hot season (in our case is the most part of the year), to facilitate radiative cooling during nights, to reduce daily temperature oscillations and to increase the temperature time lag. As can be seen at Table 1, cellular blocks have low thermal conductivity and earth blocks provide high heat capacity. The thermal absorptivity of the external side of the wall (both wall materials) is low, about 0.3. The effects of both materials properties on indoor temperature can be analyzed with the measurements.

![Image](image1.png)

**Fig 3.** (a) Hobo sensor in the cellular concrete block wall; (b) Hobo sensor in the stabilized earth block wall. In both cases are on internal surfaces. Indoor air temperature Hobos (hanging from the ceiling) are also shown in both images.

The superficial temperatures sensors were located on the East wall and, as mentioned, on the interior and exterior sides of both materials (Fig. 3 and 4 (c)). The indoor air temperature has been also measured, and the climatological variables have been taken from the weather station of the Laboratory of Energy and Environment in Architecture, located 100 m away from the house. Two periods have been chosen to analyze the thermal behavior, corresponding to the representative local seasons (hot and temperate). There were sunny days during measurements, with no changes in the climate conditions. The thermal behavior of both materials of the monitored wall has been analyzed.

### 3. Superficial temperatures in the envelope

For a preliminary analysis, infrared images of the four façades of the house have been taken (Fig. 4). The superficial temperatures vary of course with time, orientation and solar incidence, and also depend on the envelope materials. The façade with the most incidence of solar radiation is the South, but in our case a regional tree partially shades the façade (Fig. 1).

At Fig. 4, infrared images of the façades are shown. They have been taken at 11 a.m. in a day of the temperate season. In the images, the “window” at the center is the infrared image, while the rest of the photograph is the normal visible daylight image, this makes easier to locate and visualize the elements. In the images, the superficial temperatures of the windows and frames are not considered. Particularly at Fig 4 c) both Hobo sensors at the external side of the East wall can be seen, located at the two different wall
materials. In the hot season, superficial temperatures can easily reach 50 or 60ºC, as can be seen in the next paragraphs.

![Thermographic images of the house envelope. (a) South façade; (b) North façade; (c) East façade; (d) West façade.](image)

For the comparison of the superficial temperatures between both wall materials, specific areas of the wall have been selected for a more detailed analysis. The areas presented no beams, columns and not any discontinuity in the construction material. In the next paragraph we describe the measurements carried out in these specific areas.

### 4. Analysis of thermal behavior according to superficial temperatures

Superficial temperature measurements have been taken from the East wall, compound of two different areas made of cellular concrete blocks and stabilized earth blocks. Measurements have been taken each 10 minutes during several weeks, but only one week of each season is presented here. The infrared images have been taken in two specific moments of one selected day of each period, when the heat fluxes had different directions, in our case about 11 a.m. to 12 p.m. and about 6 p.m. to 8 p.m., depending on the season. Mean values of the selected areas (area between red marks at Fig. 5) have been used as instant data of the surface.
At Fig. 6, a week of superficial temperatures in the internal and external part of the two materials can be seen. At Fig. 7, only the last day of Fig’s 6 measurements is plotted, together with the outdoor air temperature, indoor air temperature and the instant data obtained from infrared images.

As can be seen at Fig. 6, the part of the wall made of cellular blocks shows more oscillation in external superficial temperatures than the earth blocks part. But on the internal surfaces, both temperatures are very similar and also time lags are similar (blue and pink lines). Although their different thermal properties, they have similar diffusivity coefficient, and thus, considering external and internal air temperatures (not superficial), they have a similar behavior considering time-dependent heat transfer.
At Fig. 7, the last day of both weeks measurements can be better appreciated. In these graphs, external and internal air temperatures have been included, for a better comprehension. We have plot the measures of one of the three indoor air temperature sensors, which were almost equivalent, probably because the indoor space is very small. Comparing internal with external superficial temperatures during morning, afternoon and night, the direction of the heat flux can be appreciated. During the morning the heat flux goes from outside to inside (external temperatures are lower than internal), during the afternoon, the direction of the heat flux goes in the other direction (external temperatures are higher than the internal). During the evening it can be seen another inversion in the heat flux, which new direction continues during the morning hours. We have selected the time to take the infrared images so that we can measured two different moments of the heat flux direction, in our case: about noon (heating period) and evening (cooling period). Comparing the sensors measurements with those obtained with infrared camera (Fig. 7), although both devices have different precision (see discussion in next paragraphs), we can see the same qualitative difference among the superficial temperature measurements in both materials, which can be better appreciated in the hot period measurements.

The thermographic images can be useful as a quick tool to study and compare the thermal behavior of different materials. Daily thermal phenomena can be study in a comparative way with this method, but of course in order to have more accurate date and to analyze thermal effects along many days, it is necessary to obtain continuous measurements during a longer period, such as those obtained from the Hobo superficial temperatures. In both cases, measurements and interpretation of superficial temperatures can be a method to study the thermal behavior of materials from which not all thermal properties are certainly known, and because of this, calculation or simulation cannot be precise.

5. Conclusion

In general, for hot dry climates, thermal strategies in buildings consist in avoiding as much as possible thermal loads during the most part of the year, to diminish the temperature oscillations and to increase the time lag of indoor temperatures in relation to the outdoor [7] [8]. As seen in the monitoring superficial temperatures, both analyzed materials seem to meet these requirements, because they reduce enough the temperature swings of the external air temperature and cause a reasonable time lag. In the cellular block wall, the external temperature increase very much and this cause a lower surface decrement factor. This is
not representative to evaluate the impact of envelope material on indoor conditions, because both materials, together with other factors, produce the same indoor temperature.

On the other hand, the thermal behavior of the envelope material has influence in general not only on the indoor conditions, but also on the thermal conditions of the surrounding spaces. In the case of the cellular block wall, the higher external superficial temperature is not adequate if there is a living space outdoors like, for example, a patio, where the effect of infrared radiation from the wall has a non-desirable impact on microclimate.

The correct application of passive thermal strategies is very important, even more in extreme climates. Part of them is to choose the adequate materials for the envelope, especially for non air-conditioned building, where the dynamic response should be considered. In many underdeveloped countries, low-cost houses often do not have access to air-conditioning devices and also their owners cannot afford the operation costs of them. The best choice of thermal properties of materials is not necessary the same if air-conditioned is used in buildings or not. In our case, both materials were adequate for no air-conditioning conditions, but in case of artificial acclimatization, cellular blocks lead to less energy consumptions, because of their lower thermal conductivity. So, in case of taking into account together (along the year) both situations: with and without air-conditioning, cellular blocks are the most adequate election, except for the negative impact on outdoor microclimates. Passive thermal strategies, in each case, can improve the indoor thermal conditions and consequently, the quality of life of people in these situations.

The monitoring of superficial temperatures has been a useful method to study the envelope thermal behavior and to analyze thermal inertia and insulation effects. For a quick quantitative analysis, thermographic images during one day can give a good idea of the thermal behavior on the envelope. Infrared images usually cannot measure a precise value of superficial temperature, because thermal emissivity of the surface is a thermal property that must be known to obtain precise measurements from the infrared cameras. Furthermore, to obtain good results, an adequate area of the envelope must be selected, without thermal discontinuities. Also an adequate time of the day must be chosen to take the images, so that different heat flux direction can be measured and analyzed.

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