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Influence of absorptance in the building envelope of affordable housing in warm dry climates

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Abstract

In Mexico, as in many other countries, the energy crisis has permeated throughout many sectors, particularly the construction sector. Mexico has started to develop and implement actions for the efficient use of energy in order to reduce its consumption. The field of building construction has been particularly active in studying ways to optimize the use of energy, especially regarding energy use indoors. One of the main goals of architectural design is to create the proper indoor conditions so individuals can carry out their daily activities in a comfortable area. Interior space must be designed and calculated to provide a comfortable temperature, appropriate lighting, sound control and ventilation for individuals to carry out their daily activities, but must also address the energy required to provide all these characteristics. In warm dry climates, air-conditioning is responsible for a significant amount of the energy consumed in buildings. Proper building design is necessary in order to reduce energy consumption in this sector.

This paper shows the results of simulations with the Energy Plus software to compare the thermal performance of a low-cost housing located in a warm dry climate, Hermosillo, Sonora, with similar construction systems in the envelope. Furthermore, an analysis of the effect of the color exterior finish, represented as a gradual change in the absorptance to solar radiation. The simulation is performed for two conditions of use of low-cost housing, the first condition considers the room without air conditioning and the second considers the air conditioned room. To simulate analyzed housing with air conditioning, is used an air conditioner from the database Energy Plus, corresponding to a Mini-split system compact unit zone cooling with a COP (Coefficient of performance) of 1.83.

Keywords: Thermal performance, low-cost housing, energy efficiency, warm dry climate, Energy Plus.

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1. Introduction

According to the National Balance of Energy of 2011 [1], the consumption of electricity in the residential and commercial buildings represents 29.2% of the total consumption of electricity in Mexico, and an important amount of this percentage corresponds to the energy used by mechanical systems for indoor air conditioning. Poor architectural design that does not take into account the diverse climates of the country's different regions has made the use of mechanical systems for air conditioning more common and necessary. The consumption of residential electricity has been continuously increasing in the last decades. It is until recently that, in the face of a global energy crisis, a few governmental agencies have started to look for ways to reduce energy consumption and to change regulations to promote energy efficiency in buildings.

Research on thermal behavior and energy consumption in buildings has become more prevalent in the last decade, due in part to the development of better and more complete simulation programs. The increased interest in this area has promoted a greater diversity in the scope of studies, from the overall evaluation of buildings to the specific analysis of the elements that have an effect on how interior spaces gain or lose heat.

The warming or cooling loads in a building depend on many variables like geographic location and climate characteristics, the construction system of the building envelope, the number of occupants, the types of activities that take place in the interior space, and the operation and maintenance of the building.

The thermal behavior of the building envelope is primarily affected by solar radiation, which is responsible for the majority of the heat gain in buildings. In regions with clear skies and warm climates, solar radiation can reach up to 1,000 W/m^2. In these regions, solar radiation is the key factor to consider when designing for indoor comfort. A poorly designed building that does not take into account the effects of solar radiation will have higher heat gains and consequently, will require the continuous use of air conditioning systems in order to ensure the comfort of indoor spaces. As a result, this building will have a higher consumption of electricity, especially during the warm season.

In 1997, Shariah et. al. [2] evaluated the influence on cooling and warming loads while using different construction systems and different absorptance coefficients on the exterior surfaces of buildings envelopes in Jordan. In addition, Berdahl and Bretz, 1997 [3]; Suehrcke et. al., 2008 [4]; Yao and Yan, 2011 [5] among others, have analyzed the relevance of using materials that reflect the solar radiation on the outer surface of the roof in order to significantly reduce thermal cooling loads.

Also, in 2012, Ma et. al., [6] analyzed the important effect that low solar absorptance and high emittance materials have over cooling loads in hot climates; whereas high solar absorptance and low emittance materials have a significant effect on heating loads in cold climates.

Libbra et. al., 2011 [7] conclude, in agreement with other authors, that any decrease in average solar reflectance of urban surfaces causes a decrease of peaks in air temperature during the summer.

Furthermore, the urban heat island effect is mainly the consequence of increased building density within cities, and the use of materials with inadequate optical and thermal properties. Various heat island effect mitigation strategies have been developed, and their effectiveness has been verified in several applications, as shown by Santamouris et. al., 2008 [8]; Synnefa et. al., 2011 [9]; Zinzi et. al., 2012 [10]; Takebayashi et. al., 2012 [11].

This paper shows results of simulations carried out with the Energy Plus software to compare the thermal performance of a low-cost housing located in a warm dry climate, Hermosillo, Sonora, with same construction systems in the envelope. Furthermore, an analysis of the effect of the color exterior finish, represented as a gradual change in the absorptances to solar radiation.

2. Case Study

In the last decade in Mexico public policies were applied that generated an accelerate growth in cities. The House Research and Documentation Center S.C. (Centro de Investigación y Documentación de la Casa, S.C., 2008) [12] reported the existence of more than 24 million dwellings in Mexico. Since the vast majority of these existing dwellings are low-cost, we will use this type of dwelling as our case of study.

2.1. Location

The building selected as a case study is located in the city of Hermosillo, in the northwestern state of Sonora. Its geographical location is at 29º 05´ North latitude and 110º 57´ West longitude, with an elevation of 216 meters above the sea level. Hermosillo has a dry warm climate with temperatures that reach a maximum high of 45°C during the months of May, June, July, August and September, while during the winter season it can reach temperatures of 5°C. The annual precipitation is 320 mm., and the city is characterized for having a clear sky with high solar radiation most days of the year.

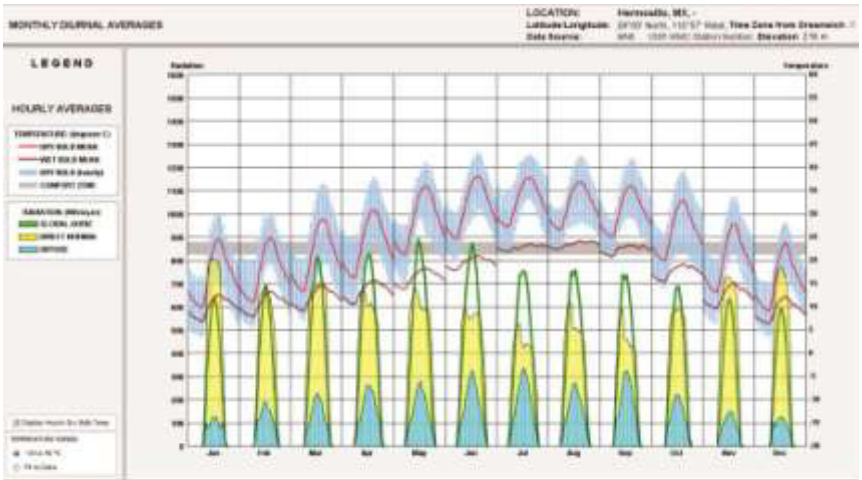

Fig. 1. Monthly diurnal averages of Hermosillo, Sonora. [13]

2.2. Building Description

The low-cost dwelling has an area of construction of 34.8 m^2, which is representative of the majority of dwellings constructed in the last decade in the city. It has two bedrooms, dining-living area, kitchen, and one bathroom in one level. See Figure 2.

Fig. 2. Schematic representation of analyzed dwelling

Construction system. The dwelling is built with 12cm thick red brick walls covered by a 1.5cm layer of gypsum plaster in both interior and exterior faces. The roof is a 10cm thick reinforced concrete slab with 2.54cm of polyurethane insulation and a simple concrete compression layer of 5 cm on top. The interior finish (ceiling) is made of a 1.5cm layer of gypsum plaster, and the exterior finish is a layer of elastomeric. Table 1, shows thermal properties of the construction system.

Table 1. Description of System construction and U values used in Thermal Simulation

Component	Description	U-Factor (*W/m^2K*)
Walls	Red brick of 12 cm thick with a thick finish of gypsum plaster of 1.5cm as interior and exterior	2.229
Roof	Reinforced concrete of 10 cm thick with polyurethane insulation of 2.54 cm, a simple concrete compression layer of 5 cm, gypsum plaster of 1.5 as interior finish and a layer of elastomeric as exterior finish	0.774

2.3. Simulation

The thermal analysis was performed using the software Design Builder, and taking advantage of its interface with the calculation program Energy Plus. The Energy Plus software is a whole building energy simulation program, that calculation methodology is based on fundamental heat balance principles.

For this analysis, the dwelling unit was considered to be one single zone, without occupants and the same construction system for both cases without and with air conditioning, only change in the envelope the solar absorptances coefficients.

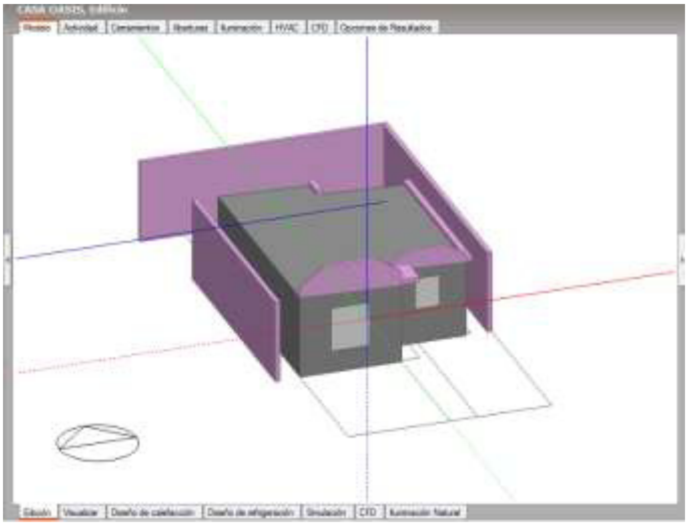

Fig. 3. Sketch of the dwelling in the software Design Builder.

To perform the analysis of the dwelling unit with air-conditioning, ventilation was not considered, only infiltration and air change. We used a Mini-Split system compact unit zone cooling with a COP of 1.83 and a design temperature of 27°C. This Air-conditioning unit was obtained from the Energy Plus database. For this analysis, cooling was considered to be on all year, while heating was never used.

In order to test the influence of absorptance in the envelope of the building, we used the same model but modified the coefficient values for the solar absorption of the building envelope. In this simulation, we used a coefficient of 0.3 and 0.5, and a coefficient of 0.7 for the roof and walls.

3. Results

The simulation was performed for the whole typical year in an hourly basis, for both cases: with and without air conditioning. For the purpose of this article, we present the values obtained during one week in the month of January, which corresponds to the winter season; and one week in the month of July, which corresponds to the summer season.

Figure 4 shows the results for the case without air conditioning during the week from the 8th to the 14th of January. The graph shows a direct effect of the solar absorption coefficient over the indoor temperature. During the hours of the day where the outdoor temperature is higher, which correspond to the hours of the day when solar radiation is also higher, the indoor temperatures have a difference of up to 2°C. This difference is caused by the absorptance coefficient of the material of the building envelope.

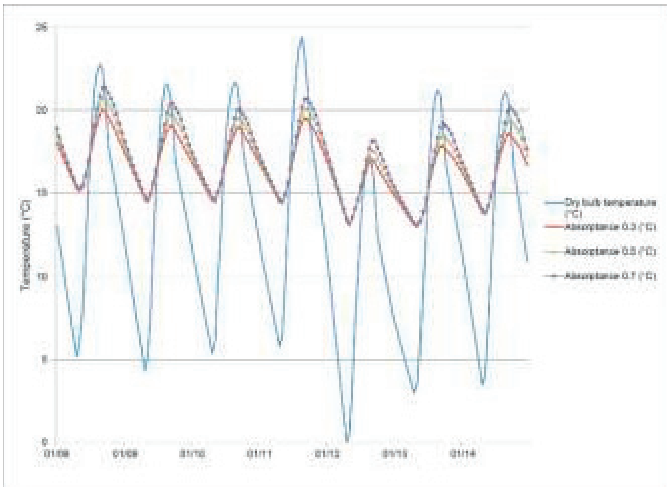

Fig. 4. Simulated indoor temperatures vs outdoor temperature for different solar absorptances, from January 8th to 14th, without A/C

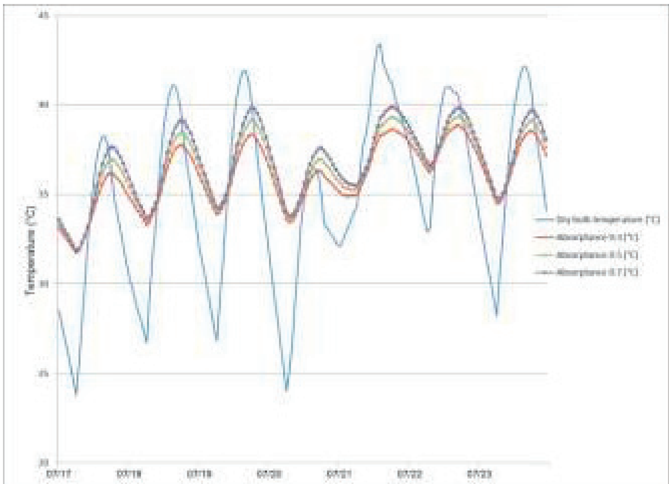

Fig. 5. Simulated indoor temperatures vs outdoor temperature for different solar absorptances, from July 17th to 23rd, without A/C.

Similarly, Figure 5 shows the results for the case without air conditioning during the week from the 17th to the 23rd of July, which corresponds to the summer season. The results are similar to those of the Winter season, but the difference in outdoor and indoor temperatures is of less than 1.7°C.

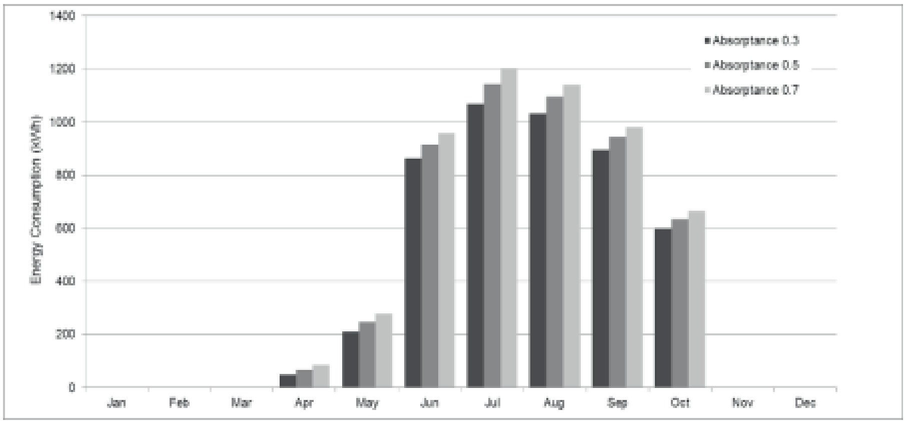

Fig. 6. Consumption of electricity for cooling dwellings with different solar absorptance coefficients in their building envelope

From the simulation of the dwelling with air conditioning, we obtained the amount of electricity necessary to maintain an interior temperature of 27°C. The results are shown in Figure 6. With a simple change of color in the interior finishes, which would correspond to a different value of solar absorptance, the amount of energy consumed can be increased or decreased. During the months when air conditioning is necessary, a variation of the solar absorptance coefficient from 0.3 to 0.5 represents a 7% reduction in energy consumption; while a variation from 0.3 to 0.7 represents a 12% reduction.

Conclusions

This paper presents the evaluation of the interior thermal behavior of a low-cost dwelling, by varying the solar absorptance coefficients of the building exterior finish. The results show that, in a warm climate region with high levels of solar radiation, the use of colors with low solar absorptance coefficients in the building envelope can significantly reduce heat gains in buildings. The colors with the lowest solar absorptance coefficients correspond to the lightest colors.

This study builds on research that supports the need to use constructive systems that take into account the climate context in order to produce more efficient buildings, by providing evidence that the absorptance coefficient of the building's exterior finishes is a relevant factor in the thermal behavior of the interior of buildings.

We conclude that, in order to achieve the optimum efficiency of a building located in dry warm weather, architects and designers must take into consideration architectural design strategies that include formal, functional and technical aspects, using passive and active strategies, which can reduce energy consumption required for interior conditioning.

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