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RESEARCH ARTICLE

THERMAL BEHAVIOR OF A HOUSE BASED ON A VOLUMETRIC THERMAL TRANSIENT MODEL

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ABSTRACT

The thermal behavior within housing obeys both to natural heat transfer processes as well as thermophysical properties of the different materials constituting the housing particularly those concerning to the envelopes such as: Ceiling, Walls and Floor. All materials are sensitive to the thermal effects and define in part the ranges of temperature values inside housing. Of a great importance also are the conditions of orientation of the house and number of openings that in turn generate air flows modifying the thermal inside conditions. On this work we analyze the influence of the envelopes on the thermal comfort inside housing, based on a computer thermal analysis and considering the material thermal properties. At the same time, we proceed to involve an experimental analysis recording temperatures gradient on different places and times inside a real house. It was performed the comparison of these results, observing in addition the regulatory standards on this matter in Mexico. The Computer Modeling was carried on through Ansys software, the developed macros includes a friendly environment during the whole process.

INTRODUCTION

The growing concern for the energy efficiency of homes in Mexico has promoted the development of various Mexican official standards as the NOM-ENER (Griego *et al*., 2012). The standards for energy efficiency in buildings represent an effort to improve the thermal design of buildings and ensure the comfort of citizens living here. The Standard NOM-020-ENER-2011 defines the envelope of a home as the set of elements which limit or make up its interior space, such as ceilings, walls, windows, doors, floors and lower surfaces. While the term of structured element refers to the combination of various materials to make an arrangement that presents constructive solutions of thermal insulation of an envelope and which can cover partial or total part of the envelope. In housing construction, the materials in use, as well an appropriate architectural design, an efficient orientation, etc. are aspects that influence the comfort of the home (Emmery, 2008). The NOM-020-ENER (energy efficiency in buildings) establishes general criteria for evaluating the overall thermal efficiency of a house, based on a so-called energy budget, determining the profits of heat. Nevertheless Temperatures data mainly for big cities are in terms of main year values. This work refer the implementation of thermal analysis procedures to different types of materials used in housing construction applicable for medium and lower cost housing and observing at the same time viable options for their use and applicability. Developed procedure involves a volumetric thermal analysis, which allows knowing the distribution of temperatures inside of the house. This result is useful to evaluate the comfort inside it. Computer procedure was performed by using finite element method for determining the volumetric distribution of the temperatures inside the house, the analytical model take into account the thermal conductivity, as well heat convection phenomena. The use of thermal insulation is one of the most effective ways of energy conservation in housing. Therefore, selection of a suitable insulating material and determination of optimum insulation thickness are particularly of the great importance (Yu *et al*., 2009).

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MATERIALS AND METHODS

Mexican Standards proposes the use of average temperatures in summer, but do not specify criteria for cold periods in winter where particularly in Queretaro State arrives to -10 ° C in some locations, so the heat loss in homes in that time is critical and the use of heating is required for the comfort of the House. Here, the thermal heating of buildings affects largely the demand peak of the electrical system, with a higher impact in Northern and coastal areas of the country. In this context, it is important to optimize the home design from the point of view of thermal behavior of the envelopes, this procedure will result in various benefits including the energy saving and the decrease of the capacity of cooling/heating equipment (CONNUE, 2012). The Standard NMX-C-460-ONNCCE-2009 incorporates relevant information that helps to reduce the use of energy in housing by concept of air conditioning to provide features that must comply with the constructive elements constituting the envelopes of the House, such as ceilings, walls and floors. This research focuses on the Queretaro city, which is located in the thermal zone 3A. The standard values of corresponding total thermal resistance R of an envelope is as follows: for walls, a minimum value R = 1.0 m^2K/W, while roofing sets a minimum value of R=1.40 m^2K/W. These required values commonly are not satisfied by current housing envelopes.

Theory and Calculations

The general equation that governs the behavior of the transient thermal 3D phenomenon in terms of a discrete model is as follows (Rao, 2011; Cengel *et al.*, 2009):

$$\rho\int c[N][N]^T dv\,\{\dot{T}\} + \rho\int c[N]\{V\}^T[B]dv\,\{T\} + \int[B]^T[D][B]dv\,\{T\} = \int[N]q^*\,d\Gamma_1 + \int\{T_B\}h_f[N]\,d\Gamma_2 + -\int h_f[N][N]^T\{Te\}d\Gamma_2 + \int\ddot{q}[N]\,dv + \{T\}_n \quad (1)$$

Where: ρ is the density of the material, variable for each envelope, c : specific heat, [N] matrix array of shape functions of the finite element, [B] is the matrix of derivatives of shape functions, {v} the velocity vector, {T} temperature vector, h_f is the convection coefficient, $\{T_B\}$ and {Te} are the temperatures vectors corresponding to the convection phenomenon, q * and $\ddot{q}$ associate the type of heat flux, and finally $\{T\}_n$ refers the nodal temperatures on discrete model.

Some consideration we have made for our case. The general model expressed here boils down to considering the term advective null, also heat generation we will not take into account by any source at the interior of the House. In that way, the resulting model is less complicated, but on the other hand we have a volumetric solution which will take into account the influence of complex envelopes. Convection Coefficient h according Szokolay (1996) assume a low wind speed in the environment close to the walls and is described by the following relation:

$$h_e = 5.0 + 4.1v \quad ; \quad h_i = \frac{h_e}{3} \quad (2)$$

Where h_e is the outer convection coefficient, h_i is the convection coefficient inner and v is the velocity of the flow air. The Bulk temperature measured in situ is a parameter required in this process. Our research describes the follow-up to each of the two both theoretical and experimental phases involved. One of the goals of this work consists in checking insulation options that improve energy efficiency. To introduce a volumetric computer simulation, we require the general geometric data of the house, Figure 1 shows a sample housing composed of various rooms. The walls, ceiling, and roof are made of typical materials used in Queretaro region (see Fig 2). Finite element procedure was done by using computer program Ansys (2011). According their nomenclature it has been applied an element SOLID70 for 3-D thermal transient analysis, this element has 8 nodes, having the possibility of downgraded to solids up to 4-node triangular pyramid type which makes it viable for meshes of complex geometry. Due to complex characteristics of envelopes, it was first developed a procedure for determining the whole thermal properties of each envelope, this procedure including some data windows was written on APDL language running on the Ansys environment. The procedure used the recommendation of the Mexican Standards.

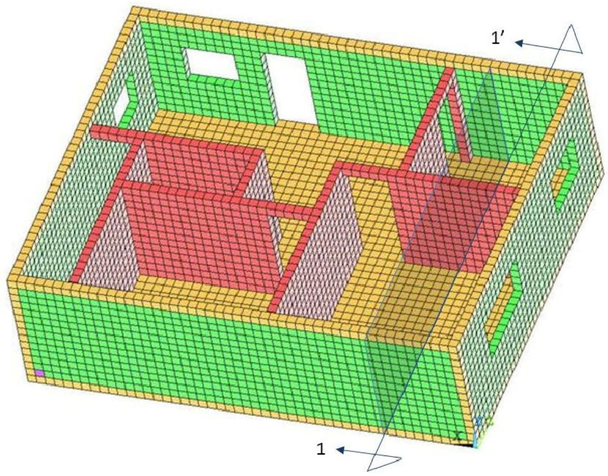
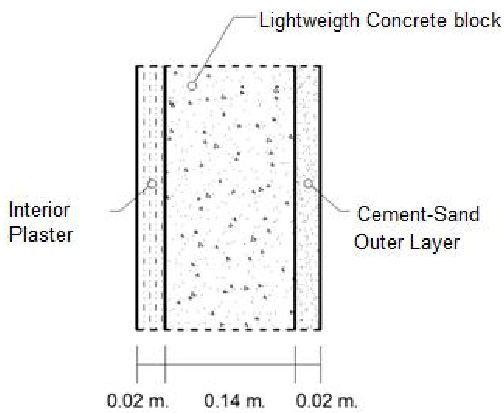
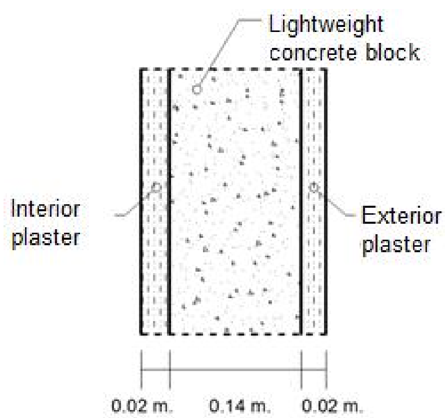


Figure 1. Volumetric finite element model of the house, an Isometric view



(a)



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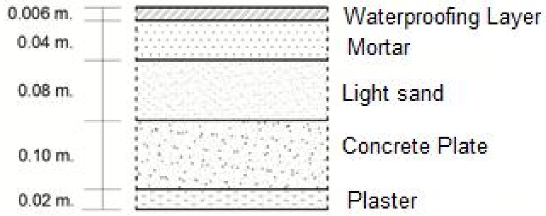

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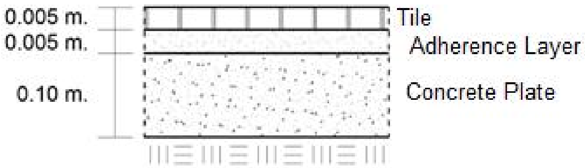

(d)

Figure 2. (a) Outer wall of the house, (b) Inner wall of the house, (c) Roof Slab, (d) Footing Slab

RESULTS

Thermal Transient case was solving including as boundary conditions the experimental data for 5 months (from January 13 to June 12, 2014) identifying the temperatures outside of the House. see Figure 3. Data are entered in the program in the form of tables of temperatures every 3 hours. Wind velocity was quiet with a low speed of 2 m/s (7.2 km/h), and which according to the relationship of Szokolay for this wind speed, convection coefficient to the outer areas was assigned a value of 14.0 W/m^2K, while the inside convection coefficient was 4.66 W/m^2K. As a sample, Figure 4 shows the temperature results inside housing on the section 1-1' (see Figure 1).To validate this computer results, we proceed to compare the registered temperatures recorded on sensor "Tint_muro_1m" located inner Housing with those obtained by modeling procedure just in the node where temperature was measured. Figure 5 shows both comparative results.

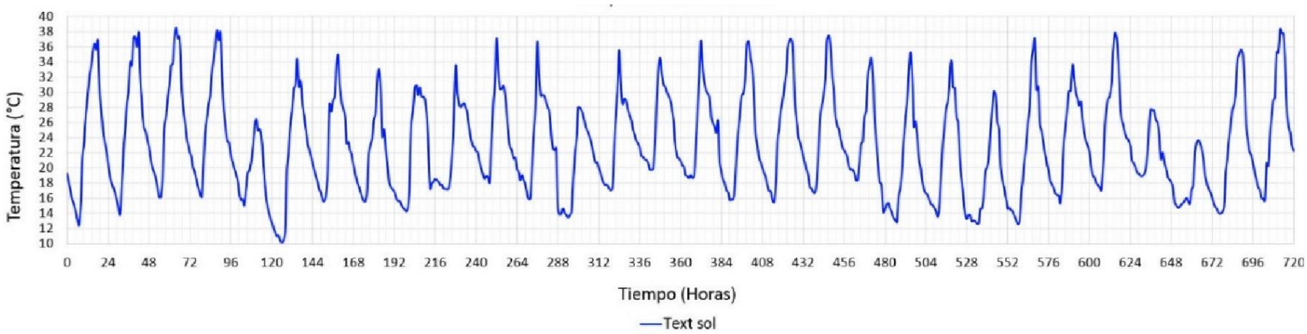

Figure 3. Experimental registered data on an outer sensor

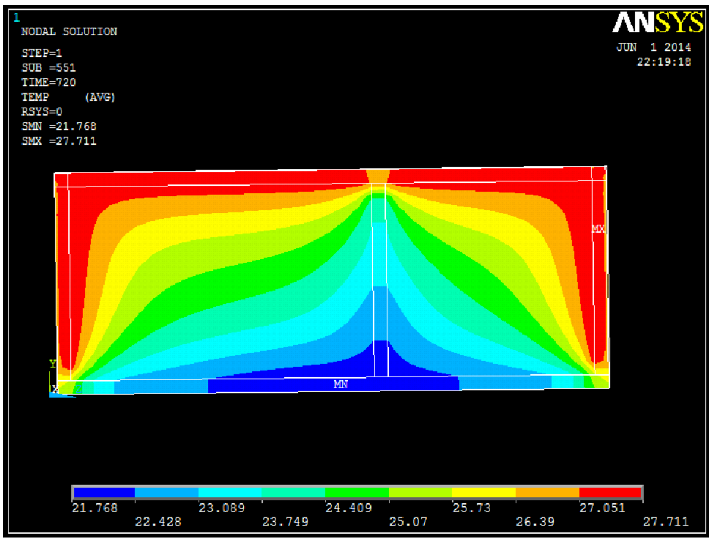

Figure 4. Volumetric thermal behavior inside the house on section 1-1'

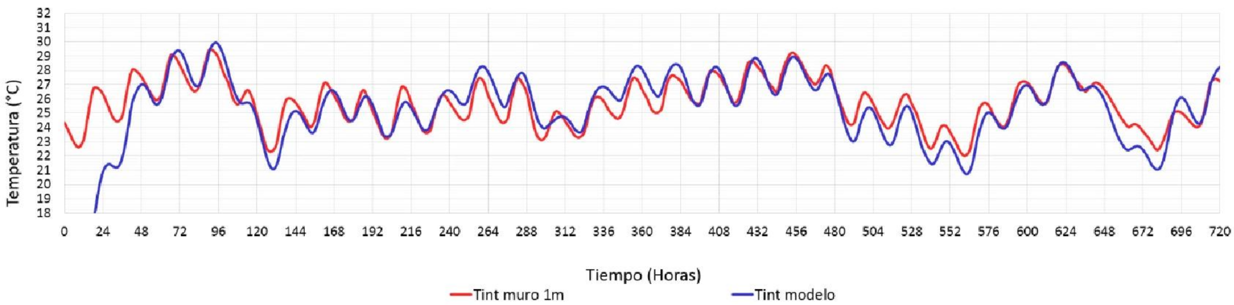

Figure 5. Comparative results of the computer modeling versus experimental ones. Red color shows levels of temperature registered by the sensor. Blue curve is the computer result obtained

So, according to this comparison, it was considered that model was properly calibrated and was reliable for the analysis of other proposed materials on the envelopes of the House, since 0.8 ° C maximum temperature differences between the curves was obtained, and according to a statistical analysis a percentage of accuracy is of the 94.3%. Note that in this graph on the beginning of the process convergence time was close to 48 hour (2 days).

DISCUSSION

It was checked the influence of expanded polystyrene (EPS) as material for thermal insulation in housing envelopes, studying the thermal behavior inside the home. This analysis was done only under a computational context. It was applied on the external walls a layer of expanded polystyrene (EPS), determining that a 1" thickness is sufficient to meet the requirements of thermal insulation according to regulations NMX-C-460-ONNCCE. Applying this change in the components of the walls, the house presents a better thermal performance decreasing the amplitude of the thermal wave generating comfort temperatures inside housing. Also it was checked that the expanded polystyrene has a better thermal performance on some other heat insulation materials such as glass wool. On the other hand, modeling in ANSYS, was used successfully to simulate the thermal behavior of the experimental prototype proposed in this methodology allowing register the temperatures distributions inside housing. The fact that the computational modeling has the advantage to be able to study the thermal behavior of a housing in a versatile manner, since the properties of the materials may vary or dimensions and its thermal characteristics, situation that is difficult to do it in a full-scale prototype since it would require to build as many as variants you wish to analyze. The objective of the study was the development of a computational tool that allows in a friendly way solve the thermal behavior of a house with complex envelopes.

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