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Ground roof as a sustainable element that improves the habitat of a space in the desert area of the northwestern border of Mexico

Cubierta de tierra como elemento sustentable que mejora el hábitat de un espacio interior en la zona desértica de la frontera del noroeste de México

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Abstract

A ground roof is a sustainable element in which using a certain thickness of ground can reach the desired thermal and climatic comfort. On the northwestern border of Mexico, with an emphasis on desert areas, there is a need to compose solutions that measure the heat gain problems caused by climatic conditions. The heat gain is caused mainly by solar rays that occur in summer; the ground roof creates an insulating layer which helps to reduce the flow of heat, which in turn with the volume of ground helps maintain and lower stable temperatures. To evaluate the thermal performance of a ground roof, with the weather conditions of the metropolitan area of Mexicali, the simulation will be carried out. The ground roof are analyzed with different ground thicknesses and measurement periods are established, according to the specifications in standards ASTMC-1046-95, ASTMC1155-95. The thicknesses were simulated with the Ener-Habitat program. In the results it has been obtained that in a concrete cover the temperatures will be higher in contrast to the temperature of the environment and that of the ground roof.

Ground roof, Thermal performance, Test module

Resumen

Una cubierta de tierra es un elemento sustentable en el que usando determinado espesor de tierra se puede llegar al confort térmico y climático deseado. En la frontera del noroeste de México, haciendo énfasis en las zonas desérticas, existe la necesidad de componer soluciones que van en medida a los problemas de ganancia de calor causadas por las condiciones climáticas. La ganancia de calor es provocada mayormente por los rayos solares que se presentan en verano; la cubierta de tierra crea una capa aislante lo que ayuda a disminuir el flujo de calor, que a su vez con el volumen de tierra ayuda a mantener y disminuir temperaturas estables. Para evaluar el desempeño térmico de una cubierta de tierra, con las condiciones climatológicas de la zona metropolitana de Mexicali, se realizará la simulación del mismo. Se analizan las cubiertas de tierra con diversos espesores de tierra y se establecen periodos de medición, según las especificaciones en Normas ASTMC-1046-95, ASTMC1155-95. Los espesores se simularon con el programa Ener-Habitat. En los resultados se ha obtenido que en una cubierta de concreto las temperaturas serán superiores en contraste a la temperatura del ambiente y la de la cubierta de tierra.

Cubierta de tierra, sustentabilidad, mejora de hábitat

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Introducction

Buildings are an important energy consumer; in the United States, energy consumption represents 40% of the total energy consumption of the country; in Mexico, 23% of the energy is spent by the domestic sector (Torres, 2000). In order to satisfy thermal comfort needs without excessive energy consumption, materials and construction systems are required to reduce heat gain to the interior of the building, and it is also favorable to use environmental adaptation techniques (Liébard and De Herde, 2005).

Buildings in hot climates need to be designed with climate adaptation systems to avoid heat saturation in the building and to reduce the heat flow to the interior. The adequate design of the architectural envelope by means of passive cooling systems has this purpose (Givoni, 1976).

In areas with extreme hot and dry climates, passive cooling systems are required in buildings in order to maintain temperatures within the thermal comfort zone, with a minimum consumption of electrical energy for artificial air conditioning (Givoni, 1998). The use of natural elements in architectural elements contributes to climate adaptation and also brings an improvement in air quality, regulates temperature and works as thermal and acoustic insulation (Garcia, 2009).

The objective of this study was to determine the thermal behavior of earthen roofs in extreme hot dry climate by means of a mathematical simulation of temperatures in test modules, to determine the temperature differences, and to perform a statistical analysis to show if there are significant differences between the interior temperature conditions of the modules and the exterior environment.

The analysis showed that with a ground roof it is possible to obtain indoor air temperature reductions in the test module of up to 10°C with outdoor air temperatures of 42°C and 5°C with outdoor air temperatures of 22°C. It was observed that there is a significant difference between the outdoor air temperature and the indoor air temperature of the test module with a ground roof.

Earth Construction

In the systems that are built with soil this is the provincial material to be used, so in order to achieve the desired characteristics for its handling and adherence, it is necessary to have a suitable granulate, which consists of having 15% clay, between 10 and 30% silt and between 55 and 75% sand, to this mixture should be added organic material such as manure which helps the different particles of the mixture to unite in a semi-uniform mixture (King, 2015).

The materials obtained from earth construction usually have a low tensile strength and good compressive strength, they are highly porous so they are very permeable to water and air, which is why they also combine perfectly with water. Earthen architecture is sustainable towards the environment and society, so the use of earth in construction is important (Jeffery, 2015).

Earthen architecture has been commonly defined as traditional, utilitarian and unsophisticated, but which responds to the immediate needs of the community by responding to climate, material and cultural expression, Earthen architecture and traditional building systems are typical of this approach. But this architecture has increasingly been a source of inspiration for a new approach to the built environment and responds to two important global challenges: sustainability and identity (Lopez, 2015).

The ground cover is composed of several layers which perform the different functions of a common thermal insulator. Generally speaking, the roof is covered with a waterproofing layer, which prevents damage to the structure (see figure 1). The soil used in a lightweight earth roof should have a low volumetric mass (800-900 kg/m3). The thickness can vary for a lightweight roof between 0.1m to 0.15m.

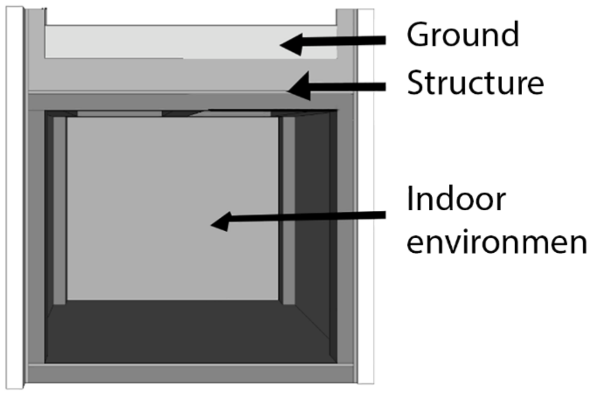

Figure 1 Earthen roof
Source. *Own Elaboration*

Method

This section describes: research design, objective, test module, parameters for the simulation and statistical analysis for the evaluation of the results. The research was of experimental type, the data were analyzed based on a statistical method (see figure 2).

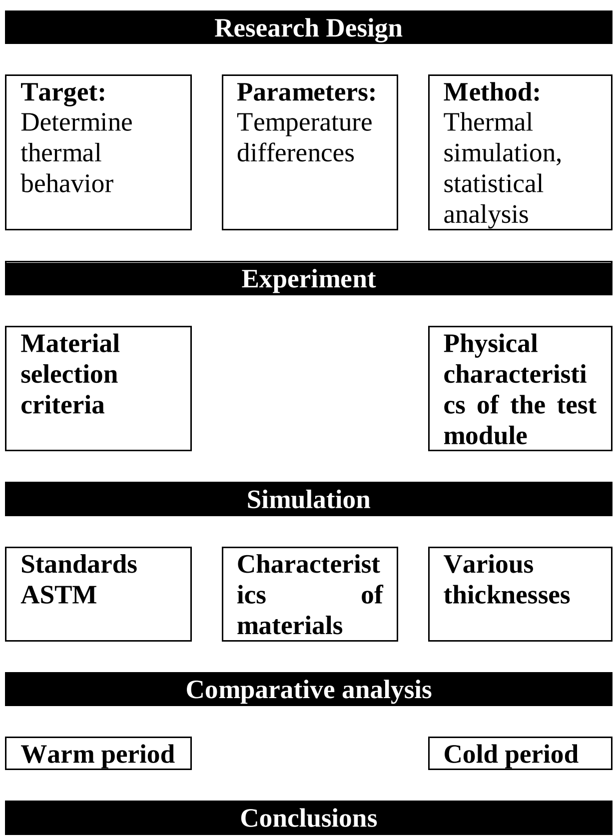

Figure 2 Research method
Source. *Own Elaboration*

The objective of the study was to determine the thermal behavior of an earthen roof in an extreme hot dry climate, for which a thermal simulation and a statistical analysis were carried out, and the temperature differences between the interior of the modules and the ambient temperature were also compared.

The method selected for the research was experimental, controlling all variables, to compare the results with each other at different times to measure the impact of the roof with soil. The verification of the data is based on a statistical analysis, where the internal temperature of the test module is considered and how it varies with respect to the temperature of the environment, with this is subjected to a comparison between two samples.

The simulation was carried out in the city of Mexicali, Baja California, a city in northwestern Mexico, located at a latitude of 32°39'54" N and longitude of 115°27'21" W, with a height above sea level of four meters. The climate is extreme hot and dry, with average maximum temperatures of 42ºC (with extreme maximums of 49ºC) and average minimum temperatures of 8ºC (with extreme minimums of -3ºC) (Luna *et al*., 2008).

The data were entered into the server program, Ener-Habitat, which performs numerical simulations of time-dependent heat transfer, thus taking into account the thermal mass effect and not only the thermal resistance. In this simulation, the system was evaluated with homogeneous soil layers, which were solved with the following formula (Figure 3).

$$\rho c \frac{\partial T}{\partial t} - k \frac{\partial^2 T}{\partial x^2} = 0$$

Figure 3 Model formula for homogeneous layered systems
Source. Ener-Habitat 2014

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Module characteristics

Several measurements will be made of earth roofs varying in their thickness, which will not have a layer greater than 10 cm of soil to avoid excessive weight of the roof (Table 2), in this way 4 measurements will be made calling each one S.C. or Constructive System, in this way the S.C.1 will be a control and will have a concrete thickness of 10cm, which will not have an additional insulating layer, the second or S.C.2 will be a concrete roof of 10cm with a protective layer of thermal insulation of 10cm. will be a control and will have a concrete thickness of 10cm, which will not have an additional insulating layer, the second or S.C.2 will be a 10cm concrete roof with a protective layer of standard polystyrene thermal insulator as second control, the third roof S.C.3 will be 10cm concrete plus a 5cm layer of soil, and the fourth roof S.C.4 will be 10cm concrete plus a 10cm layer of soil. For details of the materials see table 1.

Characteristics of the materials used			
	Thermal Conductivity W/m°C	Density Kg/m³	Specific heat J/kg°C
Earth	0.95	1600	920
Concrete	2	2400	1000
Polystyrene	0.04	15	1400

Table 1 Thermal and physical properties of materials
Sources. *Ener-Habitat 2011*

There will be two measurement periods of one month each; the first one in July where warm temperatures will be measured and the second one in January where cold temperatures will be collected, the indoor temperature will be recorded.

Name	Description
S.C.1	Concrete 10cm
S.C.2	Concrete 10cm + Polystyrene 2.54cm
S.C.3	Concrete 10cm + Earth 5cm
S.C.4	Concrete 10cm + Earth 10cm

Table 2 Construction Systems Abbreviations
Source. Own Elaboration

Results

In the simulation in the month of July it could be observed that the interior temperatures remained lower in the maximum peaks compared to the exterior, but in the valleys they remained higher, also it could be seen that between the two different types of soil thicknesses it could be observed that the thicker the layer the tendency to stabilize the temperature of the interior, It can also be seen how the control ceiling raises temperatures up to 25 degrees above the ambient temperature, while the ceiling with polystyrene was the one that remained more stable between its maximum and minimum, but always above 50 degrees Celsius (Figure 4, July).

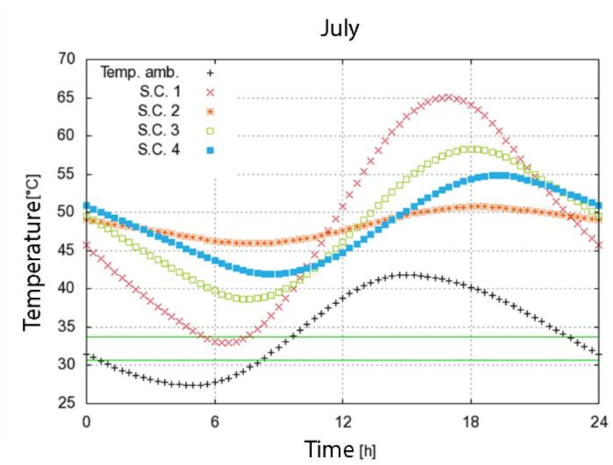

Figure 4 Summer temperaturas
Source. Own Elaboration

In the simulation for the month of January, it was observed that the maximum temperatures of the two soil thicknesses remained below the ambient temperature for most of the time, with the exception of the 5 cm roof, which remained for a longer time within the comfort zone compared to the ambient and the rest of the roofs; in the minimum temperatures, all the roofs remained above the minimum temperatures, On the other hand, the SC1 witness roof remained almost at the same level as the maximum temperatures until after midday, when it rises up to 5 degrees more, where the tendency is similar to the summer period, when increasing the layers of soil tends to stabilize the internal temperatures, while the polystyrene roof is the most stable, but as in the summer, it remains outside the comfort temperatures at all times (Figure 5, January).

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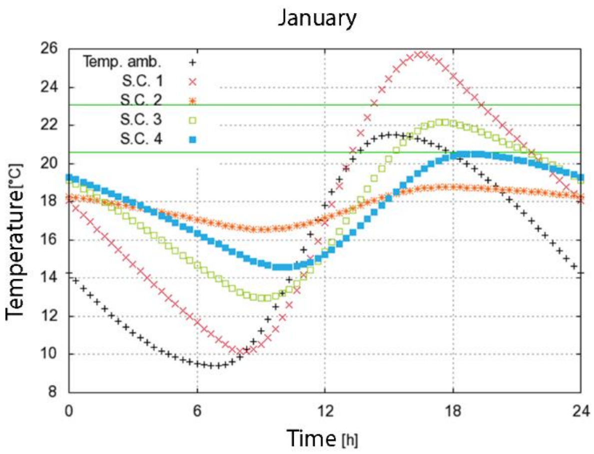

Figure 5 Winter temperatures
Source. Own elaboration

Conclusions

It is feasible to use an earth roof system in dry weather due to the thermal mass that causes a thermal lag and a reduction of heat transfer indoors.

The maximum thickness of an earthen roof of 15 cm is shown to have a higher efficiency in terms of heat transfer reduction in both summer and winter periods.

It is necessary to continue with the research where factors that did not fall within the scope of the investigation are considered and to complete the work done, aiming at having strategies in the building and in the urban environment that consider achieving greater efficiency to achieve temperatures in the comfort zone.

The economic recovery analysis should define from the beginning what will be the purpose of the earthen roof chosen, since a roof with a very thick layer of earth represents additional expenses such as the analysis of the reinforcement of the structures.

The statistical analysis showed that the difference between the indoor and ambient temperatures is significant, thus demonstrating that both modules with an earthen roof approach thermal comfort conditions with respect to the ambient, and when comparing the indoor temperatures of the two modules, the earthen roof proved to be significantly superior in terms of time within the comfort zone with respect to the polystyrene roof and the concrete-only roof.

The roof with the best results in reducing the temperature inside the module was the 15cm earth roof (see Figures 4 and 5), both roofs require special installation, but initially the earth roof is more expensive to install, increasing the price of the roof by 1% (Pilar *et al*., 2010).

In extreme dry hot weather, the earthen roof proved to be more efficient in reducing the heat flow into the module, both in the warm period and in the winter period.

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