Evaluation of the thermal performance of the envelope of an innovative construction system for low cost buildings

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ABSTRACT

This research work presents the experimental results of the thermal performance of the envelope of a prototype low cost house built in a new sustainable community located in a prevailing temperate climate, with extreme diurnal and seasonal temperature swings. This project is based on the application of an ecological and innovative building system, aimed at reducing construction costs whilst providing suitable indoor thermal comfort for the occupants, as well as high levels of self-sufficiency in energy and water, among other benefits. Previous results have shown that the application of innovative building materials and construction systems integrated with bioclimatic design techniques with a sustainable approach are a promising alternative to reduce the costs of housing whilst providing suitable indoor thermal comfort conditions for occupants, and improving their economy and quality of living as well as the environmental conditions of the region. It is expected that this approach can also be applied to promote beneficial multiple effects in the country, and if applied at massive levels, it can generate a favourable cascade effect and contribute to improve occupants’ comfort conditions, and to reduce the high housing deficit in the country whilst reducing the severe environmental damage, meant to effectively promote sustainability at regional, national and global levels.

1. INTRODUCTION

At present, the great majority of buildings located in urban centres and in rural areas incorporates architectural styles and materials that ignore the local climatic conditions as well as the cultural, social and economic interactions. As a result, such buildings, using expensive heating, cooling and lighting systems are highly dependent on mechanical and electrical systems to control the indoor environment of occupants. This situation in turn provokes the consumption of large quantities of fossil fuels that causes a severe negative impact on the environment. Therefore, it is necessary to modify these trends and to apply corrective measures oriented towards the application of sustainable actions in buildings and communities likewise.

In this research work, bioclimatic design principles and strategies, integrated with sustainable technologies and environmental planning for a housing prototype have been applied, as part of a new ecological sustainable community. The main component of the case study building is its envelope which plays an important role for achieving comfortable conditions of the occupants. This is particularly important as the building envelope built is a component of a new construction system.

The case study building is located in a typical rural region of Mexico. The main objective of this project is evaluate the thermal performance of the building envelope of the new construction system aimed at promoting its application in other locations were the cost of housing is a burden and to contribute to improve the inhabitants economy by means of a systematic training for supervised self-construction and to generate productive projects at regional levels. As a general objective, this project is also aimed at integrating sustainable technologies into bioclimatic architectural design and regional planning, based on the utilization of renewable energies aimed at promoting a consistent sustainable development in rural areas. It is expected that the results of this project can contribute to the accomplishment of a demonstrative example to generate a multiple and favourable effect in the country to improve comfort conditions of these type of buildings and to eventually improve and preserve the natural environment and the quality of living, so that practitioners, decision-makers and researchers, through the results and experiences of this project, may have a useful source of information for a consistent application of sustainability.

2. THE CASE STUDY BUILDING. USE OF NEW BUIDING MATERIALS AND CONSTRUCTION SYSTEMS

2.1 The role of the envelope in the building performance

The envelope of the building includes walls, roof, floors and windows, among others, that is, all the building components directly in contact with the external ambient conditions. The envelope of the building plays a very important role for achieving comfort conditions of the occupants in a building. In this project, an innovative building envelope has been investigated and its thermal performance evaluated.

2.2 Use of building materials for low cost housing

At present, the use of industrialized building materials has become very common in Mexico, whilst the use of traditional and indigenous materials has been declining and under-valuated in most areas of the country. The cost of land has also increased at very high rates due to speculative commercial interests. These factors have provoked a huge increase in the cost of houses and this in turn prevents the potential users to afford this basic infrastructure. Neither the public nor the private institutions can build the vast number of houses needed to comply with the demand. Besides, the users have lost the ability to design and self-construct their own houses in most regions of the country.

As to availability, apart from a large stock of conventional building materials, Mexico has also large quantities of indigenous or traditional construction materials, such as earth, adobe, stone, bamboo, thatch, etc., which are available in most locations of the country.

However, the use of these materials has been declined due to the loss of capability using traditional construction methods in their application by local builders. In most cases most traditional materials, proven to be very effective for providing comfortable conditions in extreme climatic conditions of traditional housing, have been superseded by new materials (Fig. 1), which in turn have affected both the inner ambient conditions of the occupants and caused an increase of energy consumption, mainly from electricity, coming form the burning of fossil fuels in power plants of the country.

Two of the main factors which also prevent people to have access to domestic dwellings are *the cost of building materials and the cost of labour*. One alternative solution to this situation is an approach in three areas:

- The use of local low-cost buildings materials,
- The use of low-cost recycling materials and,
- The application of simple self-construction methods through technical training of local people.

The application of sustainable actions in these three areas has the potential to reduce the cost of housing for both building materials and labour, and this in turn can also promote an increase in the rate of housing which can eventually reduce the high deficit in the country, among other benefits.

2.3 Main climate characteristics of the location of the case study building

The house is located in a typical rural area, with a climate characterized by large daily and sea-

Figure 1: Typical Mayan house with previous thatch roof, substituted by a “modern” galvanized material.

sonal temperature swings. In winter, dry bulb temperatures ranges from –1 °C to 22.2 °C, with a temperature differential of 23.2 K. In Summer, temperature ranges from 6.8 °C to 26.4 °C, with a 19.6 K temperature differential.

Mean relative humidity in the rainy season is 72%, and in the dry season is 51%. Annual solar radiation is 19 MJ/m^2, being 15 MJ/m^2 in the lowest mean monthly in Winter and 21.7 MJ/m^2 as the mean monthly in Summer. Annual precipitation is 522 mm. Prevailing wind comes from Northeast and have a relatively strong pattern, ranging from 4 to 6 m/sec.

2.4 Innovative construction system of the envelope of the he case study building

It is uncontroversial to mention that one alternative to meet the housing demand in Mexico is the use of low-cost materials and self-construction methods, associated with appropriate training directed to local people. The use of adobe as a local material for reducing cost is an important alternative as long as it is combined with a suitable training program and particularly implemented with structural capabilities for use in high seismic areas in the country.

As one of the objectives of this project was to investigate the performance of an envelope of an innovative building material, various alternatives were proposed and for this particular research work, empty plastic bottles were selected for implementation on the case study building.

This approach is meant to use *recycling materials*, such as those consisted of empty plastic bottles, widely used in the country, and technically known as PET (polyethylene terephalate) (Fig. 2).

Figure 2: Typical bottled water used as recycling building material in empty containers of up to 3.3 litres.

Previous studies have shown that the use of PET, as a basic building material is a promising approach that can be used to reduce construction costs as well as to provide other benefits (García Chávez, 2002a, 2002b, 2004). PET is an ideal container material, widely used for carbonated drinks and other liquids. Because PET is inert and of endless durability, it remains unchanged for centuries (From 100 to 1000 years). These features make PET a suitable material for recycling and for using it for other applications. However, the common practice worldwide is simply to throw the empty bottles away after being used, in spite of environmental pressure by activist to local governments to make them a priority for recycling efforts to preserve the environment.

According to recent information, Mexico is the second world consumer, after the USA, of soda beverage which uses mainly plastic PET bottles as a container. Every person in Mexico consumes 150 litres of soda beverage per year, which at national level represents 15×10^9 units of PET bottles of 1 litre or 30×10^9 PET bottles of 500 ml (Beverage Digest, 2003). Apart from this high consumption of PET, inhabitants of Mexico consume large amounts of bottled water, which containers are also made of PET, and that can also be used for practical purposes. Recent figures indicate that Mexico is the largest market of bottled water in the world (Universoe, 2005). The annual consumption of this product is 15,462 millions of litres, being 13,678 millions of litres in big containers of about 20 litres each and 1,784 million of litres correspond to PET bottles of up to 3.3 litres. Taking into account these figures, there is a large amount of useful material which should be otherwise better used for recycling purposes.

As related to construction using innovative materials, previous studies have shown that PET is a promising alternative to conventional building materials for both external and internal walls and for roofs, provided it is based on a well designed building and modular system (García Chávez, 2002a, 2002b, 2004).

The main advantages of this innovative building and recycling alternative compared to conventional building materials are: Good structural capabilities, lower cost, good thermal and weather proof performance, and easier construction and maintenance work. There is also an

Figure 3: Construction process of PET modules. Perimeter steel frame and wire enclose of bottles.

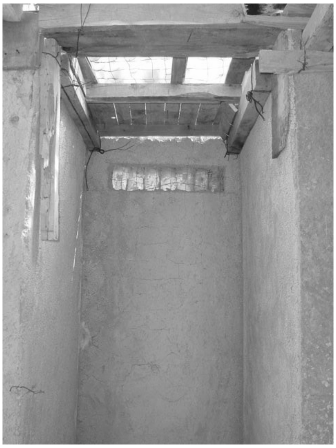

Figure 4: ECOPET 21 construction system used for walls and roof.

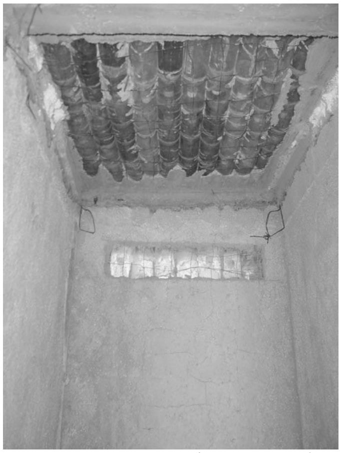

Figure 5: ECOPET 21 construction system Shown on walls and roof.

evident environmental benefit in using PET material for buildings as the dumping of this to the environment can be significantly reduced.

2.5 Construction method using PET as a building material

The construction method of the case study building consisted of: Walls, made of recycling plastic PET bottle panels, 240 cm height x 120 cm width, x 10 cm thick (Fig. 3). This particular ecological construction system has been called ECOPET 21 by the author of this work. A basic modular net of 90 cm x 90 cm at interior planes, was used in the project design. The plastic PET panels were produced based on this modular principle. Two 2.5 cm layers of sand-mortar were used on each side of the walls plaster, to make a 15 cm total wall thickness.

The roof of this house was built of two layers or double thickness of the same material as the walls, with a 25 cm total thickness, taking into account a 5 cm structural concrete compression layer with a 10 x 10 steel grid in between (Figs. 4 and 5). The house was built by local people, trained in *supervised self-construction*. Women and children participated very actively in the process, mainly in the elaboration of the recycling plastic PET bottle panels. The typical module of 240 cm height x 120 cm width, x 10 cm thick was used as the basic reference and sub-modules from these parametric dimensions were also built according to the needs of the project design and aimed at optimizing the construction process. The final appearance of the prototype house after completion is very similar to a conventional house of the location (Figs. 6 and 7).

This research project is the result of a coordinated program being carried out in the community and is based on training the people on how to build their house through *supervised self-construction*. The principle behind this program is that a selected team of local people is trained on how to build their own house and once they are skilled in the building process they become the new trainers of the following trainee's team to build their house and this generates a favourable multiple effect within a virtuous circle.

In this project, apart from applying bioclimatic design based on passive solar techniques and using the building envelope for providing thermal comfort to the occupants, daylighting strategies integrated with energy efficient electric equipments have also been implemented (Fig. 8).

The solar energy and sustainable technologies integrated in the house included a: 1 kW PV’s system; a 200 liters solar collector for water heating; a solar cooker; a solar refrigerator; a solar distiller; a solar drier; and firewood high thermal efficiency saving stove. For water use, a rainwater collection and storage system, an ecological sewage treatment plant, a grey water recycling system, a rainwater absorption well to stabilize ground water table; and the use of low consumption and water use efficient devices. As to waste treatment, a new culture will be implemented in the case study prototype, based on a sustainable recycling program.


Figure 6: Main façade of the prototype house.

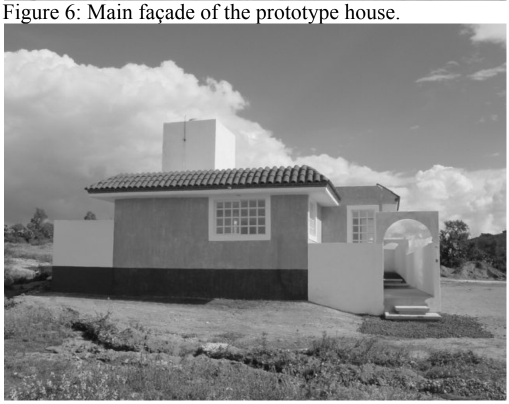
Figure 7: North façade of the house prototype.

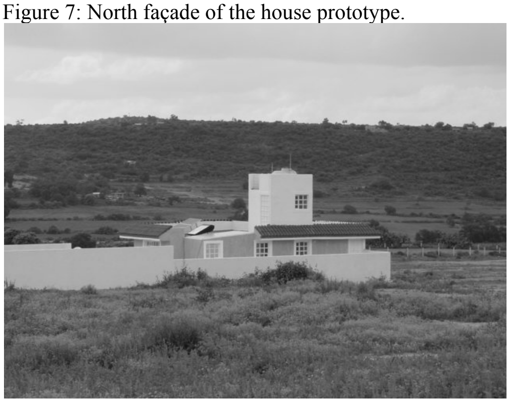
Figure 8: Prototype house. General view from southeast showing solar energy and sustainable technology systems.

The prototype house integrates also a family vegetable garden; an orchard; and includes also as supplementary food production and life-support systems: An aquaculture pond with trout, tilapia and carp; a digester, and a farm area with chickens, rabbits and bees. The inhabitants of the community will also be trained on how to construct, operate and maintain these systems in their houses.

3. THERMAL PERFORMANCE OF THE ENVELOPE OF THE HOUSE PROTOYPE

The following stage of this project included the monitoring of the thermal performance of the envelope of the prototype house, and was conducted on a ten minute base for a period of eighteen days during the typical cold and hot periods of the location. Previous studies have shown that this type of innovative building system has the potential to provide comfort conditions during the prevailing critical underheating period in a location with similar climatic conditions (Garcia Chavez, 2002a, 2002b).

Monitoring of ambient conditions in the prototype house. Analysis of results and interpretation

The equipment used for the monitoring consisted of HOBO H8 data loggers, used for measuring both internal and external ambient conditions. For indoor conditions, the monitoring process was conducted during typical underheating and overheating periods and included dry bulb ambient temperatures, relative humidity and illuminance levels. Monitoring of these conditions took place during a typical cold season in winter in January 2003 and in summer in May 2004, respectively.

The external conditions recorded were dry bulb ambient temperature, relative humidity, solar radiation and wind speed. Monitoring was conducted on a ten minute base for a period of eighteen days. Results showed that indoor dry bulb temperatures remained mostly within the comfort zone (18 °C - 26° C) for this location through the monitoring process. The lowest indoor temperature recorded was 14 °C in the coldest day of monitoring, when external temperature was 3 °C (Fig. 9).

4. ECONOMIC ANALYSIS OF THE COST OF THE INNOVATIVE CONSTRUCTION METHOD ECOPET 21

According to the economic analysis conducted for the prototype house, using recycling plastic PET bottle panels on walls and roof, there is a 40% reduction of total cost. The breakdown of the different cost components showed that by using local hand work to build the panels reduction can be up to 60%, relative to conventional brick or concrete block walls.

The total unit cost of the construction was reduced from \$ 150 US Dlls/m^2 to \$ 90 US Dlls/m^2.

Therefore, the use of innovative building materials is an effective alternative to reduce construction costs of typical houses located in rural locations and this can also contribute to reduce the current house deficit in Mexico. In terms of time of the realization of the construction, there was a 30% reduction in the case study house, relative to a conventional house of similar conditions. It is expected that this time can be even shorter, that is more favorable, when more expertise in the house construction of this type is achieved by local builders. Furthermore, the trained local people can also have this activity as a promising alternative to have access to job opportunities and productive projects in the community, aimed to reduce people migration and to assist in providing economical means to mitigate the extreme poverty conditions of their families.

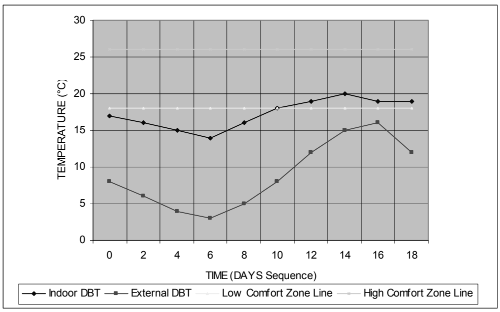

Figure 9: Typical underheating period. Sequence of eighteen days of monitoring of the average of the indoor air dry bulb temperatures relative to external dry bulb temperature and compared to comfort zone boundaries.

5. BENEFITS OF THE IMPLEMENTATION OF ECOPET 21. SOCIAL AND ENVIRONMENTAL BEBEFITS USING IT AS A BUILDING ENVELOPE

Apart from the promising approach of the application of innovative building systems using low cost materials such as PET 21 for achieving occupants' comfortable conditions in typical buildings of rural communities, there is an additional benefit regarding the contribution to reduce the house deficit in the country. Therefore, this can be a key factor to promote an increase of house construction in Mexico.

Furthermore, the use of these type of materials have also some other environmental and social benefits such as the resulting reduction of environmental damage; a promising platform for creating jobs and productive projects in poor rural regions; as well as forming the basis for generating building examples which can be used to promote a multiple and positive effect in Mexico. The preservation and improvement of the environment is a key issue in Mexico, not only in urban, but in rural areas as well.

6. CONCLUSIONS

According to the results obtained in this research project, the use of innovative building materials in the envelope of the building investigated using PET, can effectively contribute to provide comfortable thermal conditions for the occupants during the prevailing underheating and overheating periods of the location, whilst positively reducing the construction cost and housing deficit in the country. This approach can also serve as a demonstrative example and thus applied to promote beneficial multiple effects in the country, and if applied at massive levels, it can not only contribute to reduce the high housing deficit in the country but also to reduce the severe environmental damage. Therefore, the sustainable design strategies, and techniques applied in this research project are aimed at helping primarily the poorest local people, based on the use of simple and recycling low-cost local materials and to generate a new culture in the use of energy and natural resources and to promote and integrate sustainability at regional and global levels for achieving quality of living and for the well being of the existing and new generations.

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