Study of the thermal behaviour of a reused rural building.

Ignacio Cañas¹, Silvia Martin¹ and Jose Maria Fuentes¹

¹Departamento de Construccion y Vias Rurales, Escuela Técnica Superior de Ingenieros Agrónomos, Avda Complutense s/n. 28040 Madrid

ABSTRACT: In this article the thermal behaviour of a reused rural building is analyzed. Spanish rural areas are suffering the problem of depopulation with the loss of lot of traditional buildings. The reuse of these buildings is a system for saving the loss of rural heritage that is causing the loss of regional identities. The particular case studied here is an old building for sheep accommodation, this type of building was common in the interior areas of Spain due to the agrarian way of life. The owners bought the building some years ago with the aim of constructing a rural hotel. For the construction of the new building they followed some criterions based on the bioclimatic design. The study carried out tries to examine the thermal behaviour of this building by means of registering the temperature and relative humidity in some points inside it. The results show that instead of the harsh climatic conditions happening outside, the interior temperature is inside the comfort limits. This study shows that the reuse of rural buildings, in addition of the economic and social advantages, is a system of reducing energy consumption in the life cycle of the building.

Conference Topic: 6, Recycled architecture (re-use, upgrading and rehabilitation of buildings)
Keywords: reuse, thermal behaviour

1. INTRODUCTION.

In Spain there is a great amount of rural buildings (rural houses, stables, agricultural machinery stores, dovecotes, ...) abandoned from the fifties due to the rural exodus.

The reuse of old buildings provide an environmental advantage because of the reduction in energy use and building materials compared to a new construction. The life cycle of reusing an old building has less steps than constructing a new one. In addition, the reuse of old buildings has social and cultural advantages, as maintenance of regional texture, scale and history, and the preservation of local identity of traditional architecture.

One of the problems about the reuse of rural buildings is their remoteness to large population centres and the poor quality of infrastructure in rural areas. New leisure alternatives offer the possibility of using again this type of buildings. Give a new use to abandoned rural buildings involves the presence of new people and activities in rural areas, therefore the economy could be improved.

In this paper the results from the monitoring of a reused rural building during summer are shown.

2. BUILDING CHARACTERISTICS.

The studied building is placed in a small town called Covachuelas in the province of Segovia (Castilla y Leon). The town was uninhabited in the fifties. The altitude is 1005 m above sea level, and it is 120 km far away from Madrid (see figure 1).

Figure 1: Map of location.
The area is characterized by a continental climate with great temperature oscillations. The absolute maximum temperature in the hottest month is 39º C, and the absolute minimum temperature in the coldest month is –15º C. The mean annual precipitation is 470 mm (see figure 2).

**Figure 2**: Summary of climatic conditions in Covachuelas. TM: monthly average of daily maximum temperature; Tm: monthly average of daily minimum temperature; P: monthly precipitation. Source: National Institute of Meteorology. Weather station in Segovia (1971 – 2000)

In the studied area there is plentiful use of earth as a building material in popular architecture. This material is very typical of some Spanish regions where the lack of another building materials joined to the good quality of their soils make it a suitable material as well as ecologic.

The old sheep house was a large building constructed of stone masonry and sun-dried bricks. When the current owners bought the building, it was almost in ruins. They wanted to build a rural accommodation. The rehabilitation process aimed at keeping the typology of regional traditional architecture as well as incorporate some building elements from bioclimatic design.

2.1. Rehabilitation characteristics:
- All building materials used in the rehabilitation works have low environmental impact.
- Compressed earth blocks were made from local soils. The use of this building material has two advantages: the same colour as that found in traditional architecture, and good thermal behaviour.
- The insulation was made of natural materials (pure wool).
- A glazed surface was constructed in a part of the roof oriented to South with the aim of making better use of solar radiation in winter (greenhouse effect). Finally, the glazed surface on the roof was larger than that calculated in the rehabilitation project due to several problems with the subvention for the solar panels.
- The drop of the terrain was used for burying in part the north façade, so it is less exposed to the environment and has high thermal inertia like underground constructions.
- The building uses renewable energy: wind power, thermal and electric solar energy.
- The plumbing system allows to separate sewage from washes and also to collect rainwater in a small pond.

**Figure 3**: The building before the rehabilitation.

**Figure 4**: The building after the rehabilitation.

**Figure 5**: Elevation of the building, showing the glazed surface on the roof oriented to South.
3. ENERGY SAVING ON BUILDING MATERIALS.

As indicated previously, the building materials used in the rehabilitation works were selected following environmental criterions. The embodied energy of the selected materials is low, so the impact derived from the construction phase is reduced (table 1).

Table 1: Embodied energy in various building materials. Source: Sinha, 1997.

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied energy (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>0,1</td>
</tr>
<tr>
<td>Natural cement</td>
<td>3,8</td>
</tr>
<tr>
<td>Plaster</td>
<td>3,1</td>
</tr>
<tr>
<td>Aluminium</td>
<td>97,2</td>
</tr>
<tr>
<td>Local wood</td>
<td>0,72</td>
</tr>
<tr>
<td>Foreign wood</td>
<td>5,04</td>
</tr>
<tr>
<td>Glass</td>
<td>28,15</td>
</tr>
<tr>
<td>Plastic</td>
<td>162</td>
</tr>
</tbody>
</table>

In addition, the reuse of the building by itself involves a reduction of the environmental impact due to the elimination of some phases of the construction cycle. In the studied case, demolition works were not required and neither land preparation jobs previous to the construction were done. Therefore, the energy needed to reuse the abandoned building is less than that needed in constructing a new building completely.

The compressed earth block technique has the next advantages:
- The compressed earth blocks can be made in the same place where the building will be constructed, by using local and plentiful material (soil), so the transport and extraction costs are almost zero.
- The thermal behaviour of compressed earth blocks is better than other building materials, so they produce energy saving on insulation as well as indoor comfort conditions (this subject is analyzed in the rest of this paper, showing the results from the monitoring) (table 2).

Table 2: Physical properties of adobe. Source: Dominguez, 1998.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1200 – 1700 kg/m³</td>
</tr>
<tr>
<td>Ice resistance</td>
<td>Low</td>
</tr>
<tr>
<td>Exposure to elements</td>
<td>Low</td>
</tr>
<tr>
<td>Specific heat</td>
<td>0.85 kJ/kg</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>0.46 – 0.81 W/mK</td>
</tr>
<tr>
<td>Thermal wave dampening coefficient (40 cm)</td>
<td>5 – 10 %</td>
</tr>
<tr>
<td>Daily gap (Outdoor – indoor thermal wave)</td>
<td>10 – 12 h</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>Good</td>
</tr>
</tbody>
</table>

- The elaboration process does not need the use of heavy machinery or working place, so the energetic cost is also very low (table 3).
- The economic saving is helped by the low cost of the soil/earth extracted from the local area.

4. MEASUREMENT SCHEME.

In order to analyze the hygro-thermal behaviour of this building, the monitoring of indoor and outdoor conditions was carried out. The measurement instruments used are:
- Data logger called Hobo H8 HR/Temp (H08-003-02) for the measuring of temperature and relative humidity inside the building. Its resolution is 0.4°C for temperature and its accuracy for relative humidity is 5%.
- Data logger called Hobo Pro HR/Temp (H08-032-08) for the measuring of the external conditions. Its resolution is 0.02°C for temperature and its accuracy for relative humidity is 3%.
- Data logger connected to a pyranometer for the measuring of the global solar radiation. Its accuracy is 2%.

Inside the building the temperature was recorded in 7 points:
(i) inside the storeroom, which is placed on the north part of the ground floor
(ii) in the kitchen, placed also in the north part on the ground floor
(iii) in the hall on the ground floor (*)
(iv) under the glazed surface, on the ground floor
(v) inside a bedroom placed in the north part on the first floor
(vi) in the corridor on the first floor (*)
(vii) in the south part on the first floor (*)

In the three points marked with asterisks, the relative humidity was also recorded.

5. RESULTS.

The results from the monitoring carried out from 11 to 27 August, 2003, are showed below. Unfortunately there have been failures in some instruments and the...
conditions in the north part on the ground floor was not measured.

5.1. Outside conditions:
The maximum temperature recorded was 38.7°C at 15:00 on August 13th, the minimum was 9.3°C at 7:00 on August, the 27th. The mean temperature was 22.9°C with an oscillation of 29.4°C. The maximum relative humidity registered was 97%, the minimum was 8% and the average was 48%. The maximum value of global solar radiation recorded was 1078 W/m².

5.2. Indoor conditions:
- Ground floor:
  On the ground floor the only recorded data are those from the south part. This zone are affected by the large glazed surface on the roof, whose purpose is to be used as a solar collector during winter time when the temperature is extremely cold.
  The maximum temperature recorded was 28.7°C at 14:00 on August, the 14th, the minimum temperature was 21.2°C at 8:00 on August, the 27th. The average temperature was 25.1°C with an oscillation of 7.5°C. The maximum relative humidity was 60%, the minimum was 21% and the average was 39%.
- First Floor:
  On the first floor there are three monitored points: the corridor, the south zone and the bedroom oriented to North.
  In the corridor the maximum temperature registered was 30.7°C from 18:30 to 19:30 on 13th of August. The minimum temperature was 19°C at 7:30 on 27th of August. The average temperature was 25.9°C with an oscillation of 11.7°C. On the other hand, the maximum relative humidity was 55%, the minimum was 24% and the average was 35%.
  In the south zone the maximum temperature registered was 34.9°C at 15:00 on 13th of August. The minimum temperature was 21.7°C. The average temperature was 26.8°C with an oscillation of 13.2°C.
  In the bedroom oriented to North the maximum temperature registered was 29.9°C from 19:30 to 00:30 on 13th of August. The minimum temperature was 21.7°C at 5:30 on 21st of August. The average temperature was 26.2°C with an oscillation of 8.2°C.
  Figures 6 and 7 show the temperature and relative humidity measurements during 4 days of monitoring (18th – 21st of August, 2003).

In figures 8, 9, 10 and 11 the level of cooling / heating registered (indoor temperature – outdoor temperature) against outdoor temperature is showed. As it can be seen in the figures, there is a clear overheating effect in the corridor and in the south zone on the first floor. The poor level of natural cooling is not able to move the points inside the comfort band (which is around 24°C ±2°C). In the corridor most of points showing discomfort due to overheating are placed between 27°C and 30°C. In the south zone the points showing overheating are above 29°C, most of them are between 26°C and 27°C (when the outdoor temperature registered is in 20% of measurements higher than 30°C). From this analysis we assert that the thermal behaviour of the building can be improved. The indoor conditions registered are much less extreme than that registered outside, however in the corridor and the south zone on the first floor there is an overheating effect.
In figure 12 the variation of indoor temperature with regard to outdoor temperature is studied. The aim of this analysis is to determine the influence of outdoor conditions on the indoor ones.

From the figure the tendency lines where calculated, where x is the outdoor temperature and y is the indoor temperature for each point:
- in the south area on the first floor the tendency line and the corresponding error factor are: 
  \[ y = 0.3379x + 19.01 \quad R^2 = 0.7408 \]
- in the bedroom oriented to North on the first floor: 
  \[ y = 0.0734x + 24.539 \quad R^2 = 0.0721 \]

The previous equations show that the temperature recorded in the south area on the first floor are more dependent on the outside temperature than that measured in the bedroom oriented to North (first floor). The results proves the effect of orientation as shock absorber. In our latitudes it is better the north orientation to achieve comfort conditions in summer.

In figure 10 the variation of indoor temperature with regard to outdoor temperature is studied. The aim of this analysis is to determine the influence of outdoor conditions on the indoor ones.

In figure 11 the variation of indoor temperature with regard to outdoor temperature is studied. The aim of this analysis is to determine the influence of outdoor conditions on the indoor ones.

6. CONCLUSIONS.

From the data analysis and despite the lack of measurements in most zones of ground floor, the next conclusions were obtained:
- In this reused rural building the conservation of the existing stone masonry walls joined to the excavation in the north part of the ground floor below the ground level, make the hydro-thermal conditions in this floor comfortable. The measurements in this floor were taken under the glazed surface. In spite of the overheating suffered in summer due to the greenhouse effect, the measurements recorded are higher than the upper comfort limit only a few time.
- In spite of the existence of a small pond for the collection of rainwater, whose main function is the control of the relative humidity, the measurements are in most cases below the lower relative humidity limit.
- The orientation is an important design element when constructing a bioclimatic building, the differences registered in zones with different orientations in the same floor prove that conclusion.
Therefore, it is possible to dampen the external thermal wave by means of a good orientation and high thermal inertia envelope. The hygro-thermal conditions on first floor could be improved by keeping the openings on the roof opened during the night, and by installing shading systems during the day.

ACKNOWLEDGEMENT
The authors wish to thank the Ministry of Science and Technology of Spain for funding the Investigation Project PB8-0720 “Aproximación a una metodología de reutilización de construcciones rurales”. The plans of the building were made by the architect Gabi Barbeta, who directed the rehabilitation project.

REFERENCES