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Underground dwellings in the Tajuña valley, Madrid, Spain and their bioclimatic adaptation

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ABSTRACT: Underground dwellings are the maximum example of the vernacular architecture adaptation to the climatic conditions in areas with high annual and daily thermal fluctuations. This paper summarizes the systematic research about the energy performance of this popular architecture and their adaptation to the outdoor conditions in the case of the low area of the River Tajuña and its surroundings. Some considerations on their maintenance and renovation arise from the research.

1 METHOD

Compilation and analysis of different sources (even conversation with citizens) as well as the development of an inventory to collect characteristics and graphic information of the caves were the steps followed on the research.

On one side, the use of the caves in time as well as their development and their gradual disappearance, as dwellings, from the middle of 20th century was analysed by the town planning evolution. It was investigated by photogrammetric flights (from 1946 up to nowadays) in addition to local, regional and national cartography. In addition, direct contact with the buildings and their ubication was essential to develop a detailed analysis of the settlement, typology and the constructive properties as well as of the bioclimatic performance.

In addition, a survey was used to get information from the citizens. In them, basic information about the type of inhabitants or the way of living was collected as well as their opinion about this type of architecture. This field work on site is still going on.

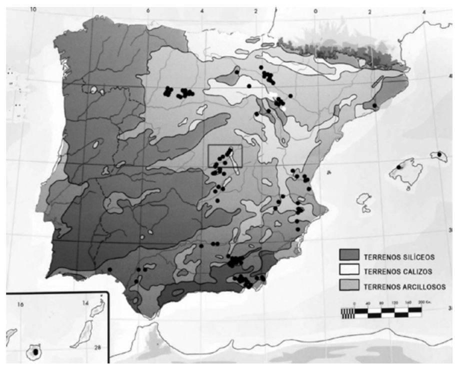

Figure 1. Lithological map with the location of the underground dwellings in Spain. As can be observed, the dwellings-caves are commonly placed in clayey lands and, to some extent, in limestone areas. There are no dwelling-caves in siliceous soils due to their hardness. Dwellings located in the River Tajuña valley are highlighted in the box. (Credits: Personal compilation/authors).

2 NATURAL ENVIRONMENT

Tajuña valley flows among deep gypsum and loam ledges in the southeast of the Madrid province. Carabaña, Tielmes, Perales de Tajuña, Morata de Tajuña, Titulcia—in the riverbank—,Valdilecha, Valdelaguna, Chinchón, Valdearacete, Brea de Tajo, Estremera, Fuentidueña de Tajo and Villamanrique de Tajo are some of the villages in which dwelling-caves are placed. The last three municipalities are placed in the catchment area of the River Tajo meanwhile Ciempozuelos is placed in the meadow of the River Jarama.

The stretch of Madrid in which the River Tajuña flows is a sheer valley between plateaus and moorlands. There are gypsum and gypsum-loams scarps modified by karst and fluvial processes, coming from an old Miocene's area of limestones and gypsum. In fact, in the bed of the river there are sand deposits from the Quaternary. The valleys of the River Jarama and the River Tajuña as well as the tributary streams and rivers are limited by huge gypsum scarps, from the Late Tertiary, with deep slopes ranging from 80–100 meters up to

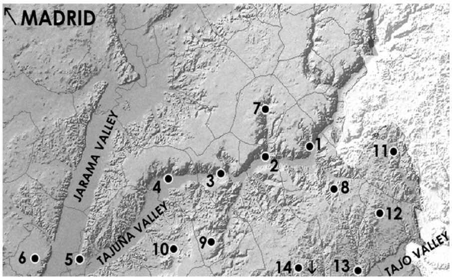

Figure 2. Situation map of the south-eastern of Madrid province with relief forms. Villages with underground dwellings were marked: 1. Carabaña; 2. Tielmes; 3. Perales de Tajuña; 4. Morata de Tajuña; 5. Titulcia; 6. Ciempozuelos; 7. Valdilecha; 8. Valdaracete; 9. Valdelaguna; 10. Chinchón; 11. Brea de Tajo; 12. Estremera; 13. Fuentidueña de Tajo; 14. Brea de Tajo. Source: Instituto de Estadística ICM/authors compilation.

Figure 3. Historically occupied caves placed in the Risco de las Cuevas (Perales de Tajuña). Source: María del Mar Barbero Barrera and Ignacio Javier Gil Crespo.

150 m (Department of Geography at Universidad Autónoma de Madrid 1992, 14).

In this case, the main geographical factors which determine the local climate of Madrid are the average elevation of the Central Plateau chain, its standstill of the cold currents coming from the North and Northwest, as well as the hydrographical net (Navajas 1983, 73–81). As result, continental Mediterranean climate characterized this region with dry and hot summers and cold winters as well as large annual and daily thermal oscillation. The maximum average temperature comes about July (23.7ºC), with a maximum diurnal temperature of about 40ºC and minimum nocturnal temperature of about 18–20ºC. It implies that the daily thermal fluctuation ranges from 15 to 18ºC. Whereas the months of December and January register the minimum average temperature (5.5ºC), with frosts since October till the beginning of June. Hence, annual thermal oscillation can beat 40ºC.

Furthermore, the area of the analysis registers the minimum precipitation in the province of Madrid. Rainfalls take placed between October and March depending on the winds, although a stable weather prevails in the 60% of the year (Department of Geography at Universidad Autónoma de Madrid 1992, 16–25).

Relative humidity also suffers vast daily and annual variations, ranging from 30% to 80%. The high relative humidity of the valley, provoked by the vegetation, the river as well as the cold air accumulation by the williwaw (Fariña Tojo 1998, 125), generates a microclimate. And, there is a high probability of fogs in the low area of the valley because of that one and the low temperatures.

3 HISTORICAL USE OF DWELLING-CAVES

In ancient times, the use of dug-caves as dwellings was a common practice. In Madrid, many of them are located in gypsum scarps along the valley of the River Tajuña. The most famous are the ones placed in Risco de las Cuevas at Perales de Tajuña. But, apart from these ones, about sixty archaeological sites in caves and natural shelters had been counted in Tielmes (de la Torre Briceño 2003, 20–31). Julio Caro Baroja (1946 [1981], 1: 311) stated that «the way of living of the shepherds [Carpetanos] was different from the Celts ones. Many of the Carpetanian cities were placed in cliffs and escarpments with natural or artificial caves, used as mansions, such as nowadays occurs in Tarancón or other villages from Cuenca. Plutarco related about the caracitanos, the city of "Caracca" by Ptolomeo . . . that there were no houses, as the most of the cities and villages, but it was a great and high mountain with many caves oriented towards the north».

Afterwards, other settler colonies (Visigoths and Muslims) adopted this kind of habitat. Hervás Herrera (1995, 187) considered that the Visigoths «occupied the area since the middle of the fifth century, taking advantages of the favourable geophysical properties, the cave-settlements and the Romans infrastructure». Later, Muslims used the caves as well and García Martín's quotation (2001, 32–33) from *Cora de Santaveria* by Al-Idrisi explained that «it was carried out the excavation of the dwellings in soft rocks, meanwhile the closure was built with mud walls, adobes and "lime and stones"».

In the Middle-Ages the current urban grid was established and the cave neighbourhoods defined. It took place after Toledo Reconquest by Alfonso VI, in the first middle of the 12th century, when the central mountain chain and the River Tajo were repopulated (1118–1157) with people coming from Segovia as well as remained Moorish. They were established in the cave-dwellings placed in the

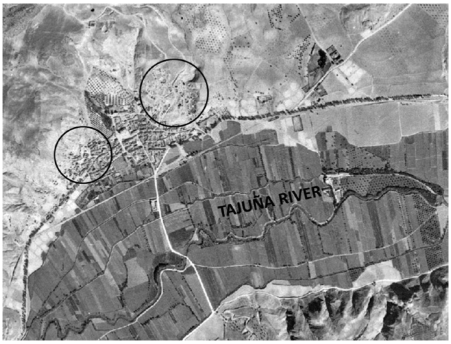

Figure 4. Ortophotography of Tielmes in 1946. The circles sign the situation of two underground dwellings neighbourhoods: Cuevas de Arriba and Cuevas de Abajo. Source: the authors over a historical map sited at planeamadrid (Dirección General de Urbanismo, Comunidad de Madrid).

Figure 5. *Cuevas de Arriba* neighbourhood nowadays, in Tielmes. Source: María del Mar Barbero Barrera and Ignacio Javier Gil Crespo.

suburbs and adopted the local constructive traditions, followed since the pre-romans.

However, the golden age of the Spanish cave-dwelling lasted from 18th century up to the middle of 20th century (Seijo Alonso 1973, 71–76). Regarding that, based on the statistical data from Madoz's dictionary (1845–50) we know that, in the middle of 19th century, Carabaña had «about 300 houses and 60 caves or soil vault», Fuentidueña de Tajo «85 houses and 45 habitable caves», Morata de Tajuña «about 400 houses, in general, with two floors and medium size, and 150 caves», Tielmes «112 houses, with 20 caves, in which inhabited more residents» and Valdearacete «280 houses, in general, of low quality construction, and 45 caves». At the same time, Chinchón counted on «984 houses, most of them of two floors and good construction … with large wineries and underground caves for the conservation of wines».

During the Spanish Civil War (1936–1939), the River Tajuña valley was a battle front and its built heritage suffered a huge destruction, especially the area comprised of between Perales de Tajuña and Titulcia. As consequence, during the post-war, the amount of cave-dwellings considerably increased. Demetrio Ramos (1957), quoted in Sandoval and Tejedor (1991, 312) counted up to 120, 235, 93, 149 and 71 caves in Carabaña, Tielmes, Perales de Tajuña, Morata de Tajuña and Titulcia, respectively. Hence, the highest and latest apogee of the dug-caves as dwellings took place in this period. They were occupied by people who had lost their homes and had financial problems, as well as the ones coming from rural areas. For them, dug-caves were the cheapest and simplest solution which was in the majority based on self-building.

However, in the middle of 20th century, the agricultural mechanization and the economic crisis provoked a massive emigration towards the urban cities, mainly Barcelona, Madrid and Bilbao. It brought about change of the social and economic models which marked the start of abandon of the cave-dwellings, in parallel with the Spanish popular architecture. Moreover, underground architecture was deeply denigrated due to «reasons of social standing which provoked that nowadays most of them [dwelling-caves] were abandoned and were about to fall down» (Navajas 1983, 173).

4 CAVED NEIGHBOURHOODS AND ARCHITECTONICAL TYPOLOGY

The settlements of the analysed region were compacted and crowded together in the hillside, hills and moorlands' edge (in «balcony») towards the south. The river-bed was no built in order to take advantage of its maximum agricultural performance and exploitation. So, settlements were lengthened on the slope when the valley was deep. The streets parallels to the river were length and horizontal following the isolines. Whereas the perpendicular ones were short, following the angle of the slope and taking advantages of the stream beds.

Furthermore, a central urban development was developed in the villages which grew around the church, a square or a main road. Everytime, the best type of soil was preserved for crops, while the settlements moved away and brought closer to the south or south-east slope of the valley. Cave-dwellings commonly were placed on the outskirts and isolated from the central urban grid. Some of those neighbourhoods and suburban slums are: Cuevas Viejas (Carabaña), Cuevas de Arriba and Cuevas de Abajo (Tielmes), Cuevas Altas, Cuevas del Calvario and el Barrio Nuevo (Perales), calle de la Morería, barrio del Calvario and Cuevas de Arganda (Morata de Tajuña), calle Palomar and el Cerrón (Titulcia), Cuevas de la Barrera, Cuevas

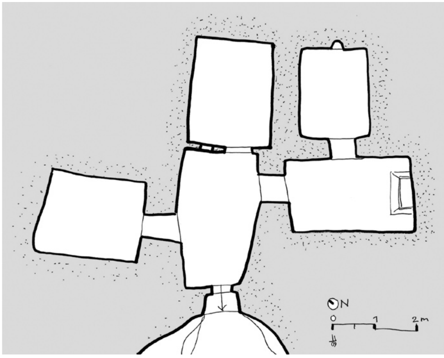

Figure 6 Plan of a cave-dwelling in Valdaracete. In this case, the entrance hall distributes the circulation towards the rest of the rooms. Source: Ignacio Javier Gil Crespo.

Figure 7. Outside image of a cave-dwelling in Valdaracete. It is dug on the slope and kitchen chimney can be observed as representative element as well as bioclimatic strategy. Source: Ignacio Javier Gil Crespo.

del Prado and Cuevas del Consuelo (Ciempozuelos), Soldellano (Valdearacete), calle de las Cuevas (Valdilecha), calle de la Cueva (Chinchón) and barrio del Sepulcro (Fuentidueña). This gap between the cave neighbourhoods and the urban grid was because of not only social reasons—Caro Baroja (1946 [1981], 2: 275–276) pointed out that in the cave-dwellings lived «poor people or people who were apart from the society»—but also constructive reasons: the geological properties of the land. As the aforementioned, the suitable soils for digging were the calcareous and the gypsum ones, placed on the slopes in escarpment and hills; meanwhile, river-bed was compounded of less consistent clayey and sandy sediments.

On the south-east of Madrid, villages and cave-dwellings were developed in areas with noticeably steep slopes. There are two main types: «firstly, a group of caves placed on severe slopes following contour-lines-streets... and, secondly, generally in hills and little valleys, amorphous groups generated an amalgam of urban spaces, irregularly connected, when caves and chimneys randomly appear» (VVAA 2004, 12: 453). The latter can be found in Morata de Tajuña, Fuentidueña or Ciempozuelos, which were dug in shrubland areas named «in plain» by Sandoval and Tejedor (1991, 314).

Concerning the layout, if there is enough space in the front, one or several rooms appear in the first bay and were commonly occupied by the kitchen and the stable; if not, dwelling-caves were developed towards the back and the entrance hall was communicated with the following spaces. In any case, exterior rooms allow the access to the interior rooms and, for instance, the larder was accessible from the kitchen, meanwhile the bedrooms were from the entrance hall. The level of the floor was usually under the one of the street and, commonly, there were not sunken floor at indoor areas. However, in some cases, the entrance hall can be over the rest of the spaces so one or two steps could be go down to go into those (Maldonado Ramos 1999, 101–109). The doors were opened in the shorter sides of the rectangular space in order to not endanger the structural stability.

In order to satisfy the gradual dweller demands, a new construction was usually added and attached to the caves to locate, initially, wet zones (kitchen and bathroom). Afterwards, these ones were enlarged to provide a winter living room, keeping the bedrooms inside the cave-spaces. These constructions could be attached to the caves, in such a way that the entrance was through them, or a courtyard could be left between both. With the time and the adaptation to the current comfort requirements, the annexed building became a whole house and spaces in the cave were set aside as storehouse or summertime bedrooms.

5 BIOCLIMATIC PERFORMANCE

Underground architecture arises as an efficient response to the climatic hostility in climates with defined continental weather. Settlement was carefully selected taking advantages of the types of soils, solar radiation as well as breezes. In addition, as result of the geographical cataloguing, it is deduced that this underground architecture is placed in semi-arid and arid areas, in order to guarantee a suitable humidity to inhabit the cave, avoiding risks such as damages by runoffs, water filtration or even sinking.

As the aforementioned, limestones and gypsum soils are common in this area to make easier the construction while structural security was preserved. They were placed on the slope where lands were released for agriculture but also guaranteed that there were no floods and water flows. At the same time, their location on the slope allows them to use the breezes of the valley while avoided the common fogs. In addition, cave-dwellings were located in the south, east or south-east slopes for the passive performance of the buildings, using the different position of the sun in winter and summertime. And, relation among dwellings prevents the solar obstruction in wintertime.

On the other hand, this type of architecture shows an optimal annual and daily thermal stability. Thermal inertia is defined as «the difficulty that offers an element to modify its temperature» (Neila González y Bedoya Frutos 1997, 251) and it is directly related to the thermal mass. The latter implicates mass (as a function of the volume and density) and specific heat which is the «amount of heat that is necessary to add to a material to increase its temperature one degree» (Loubes 1985, 125).

Time lag and decrement factor of the most unfavourable constructive system of these constructions: the external walls, makes almost completely stable indoor temperatures, taking into account that their thicknesses are commonly over 100 centimetres. Land thermal gradient, on its part, depends on the type of soil, its humidity and vegetation, the deepness as well as the climatic conditions. Although, daily thermal oscillation commonly wears off between 50 and 75 centimetres of deepness, and the annual one is neutralized at about 10–12 meters. In any case, an alteration of the isothermal curves was observed in the presence of holes in such a way that the temperature of them is higher than that which corresponds to the same level (Neila González 2000, 21–22). In the case of the caves on slopes, which are the predominant type in the River Tajuña valley, the distance between the cave and the surface was variable and increased with the deepness of the dwelling. Hence, interior rooms are closed to the annual average temperature, while the daily average temperature is preserved in the exterior ones.

Once the thermal oscillation was omitted, in the case of interior rooms, internal sources such as the use of the space by inhabitants and animals as well as of the kitchen is enough to achieve comfort conditions, as can be observed in Figure 8 (below). They keep their average temperature over 14ºC which afford to go inside of the comfort area with the internal gains coming from the use of the spaces.

In the case of the exterior rooms, the necessity of thermal gains is clear in the Givoni's bioclimatic chart (1969). Thermal gains by solar radiation are used in these cases, south façade and the urban plan guaranteed the use of the sun in wintertime while the thickness of the wall assured its rejection in summertime. In addition, the use of some rooms and their location in the dwellings, such as

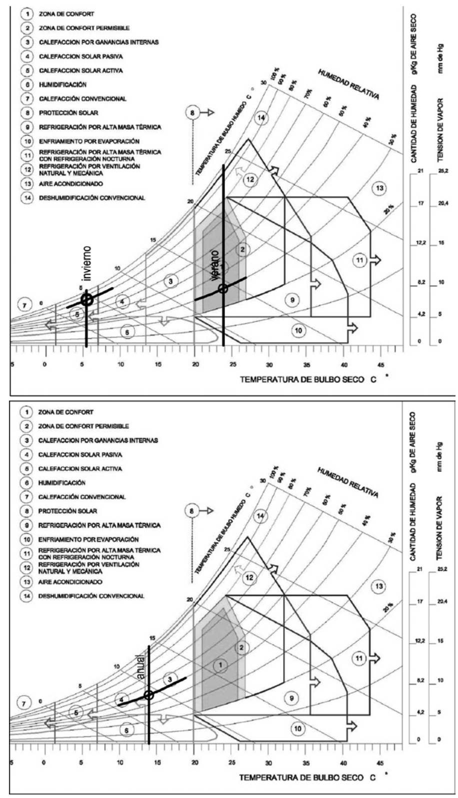

Figure 8. Summarize of the Givoni's bioclimatic chart analysis for two spaces: a room near the façade (above) and interior one (below). In the first room, daily average temperature is constant, ranging between 5.5ºC and 23.7 ºC, while relative humidity ranges between 30% and 80%. In contrast, interior rooms keep the annual average temperature and the average relative humidity which are 14ºC and 50%, respectively. Source: the authors.

the kitchen, play an essential point in the comfort conditions, because they commonly act as thermal cushions and provide an extra amount heat. Apart from the kitchen, the presence of animals inside the dwellings is a common practice in the Spanish rural environment up to some decades ago because they also favoured the heating of the spaces.

In summertime, overheat is eliminated by cross ventilation between windows and doors and the chimney. The latter is one of the most emblematic elements of this type of architecture which stand out over the slope of the hill. Their presence is essential because ventilation guaranteed the elimination of the humidity in the spaces, preserving inside comfort conditions but also the structural stability of the construction.

Hence, in underground dwellings thermal inertia strategy is complemented with a suitable selection

Figure 9. Chimneys in Tielmes. Source: María del Mar Barbero Barrera and Ignacio Javier Gil Crespo.

of the settlement and urban plan as well as the ventilation through façade and chimneys.

Nowadays, the performance of the cave-dwellings has been modified due to urban modifications towards a more waterproof surface (which could provoke an increase of the relative humidity in the caves), as well as volume alterations of the houses and the use of non-traditional materials. Under these circumstances, solar gains as well as the use of the breezes to refrigerate the rooms and dehumidify are difficult. Furthermore, the latter is one of the main problems to face up to because not only bioclimatic behaviour is endangered but also structural stability.

6 CONCLUSIONS

For the aforementioned, two main types of bioclimatic-performance strategies were found. Firstly, the selection of the settlement on a slope that released the riverbank for agriculture avoiding the water flows and the fogs. At the same time, it allows the use of the breezes to ventilate internal spaces to prevent overheat and eliminate the excess of the humidity. The south, east or south-east orientation of the slopes and the urban plan take advantages of the solar radiation on the caves in wintertime.

Secondly, the passive performance of the buildings and their huge thermal inertia with daily and, in some cases, even annual constant temperatures is highlighted. External walls act as thermal regulators built on thick mud or adobe (Maldonado Ramos, Rivera Gámez y Vela Cossío 2002) and their thicknesses not only warrant a thermal stability but also the rejection of the solar radiation in summertime. In addition, distribution is carefully organized to favour construction adaptation to the climatic conditions.

Finally, since this type of architecture is in symbiosis with the environmental and climatic conditions, the latters should be analysed previously to make a decision about maintenance or renovation.

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