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Energy efficient underground construction: natural ventilation during hot periods

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Abstract. Underground construction is a viable alternative to conventional design, especially in climates with harsh ambient conditions. In this research we analyze the natural ventilation in underground constructions, focusing on the entrance tunnel and ventilation chimney. We analyze how the differences between indoor and outdoor temperature influence the natural ventilation during periods of high outside temperature. The effect of natural ventilation in the cave ambience is also studied. For that purpose, a monitoring plan that consists of 57 sensors placed strategically according to the constructive design of the building was designed. Results show the influence of outside temperature, ventilation chimney and access tunnel on the conditions inside the underground construction. When the outside temperature is high, the design of these buildings reduces external fluctuations and the effect on the inside ambience is negligible. Due to the scarce natural ventilation (even during the night), forced ventilation is necessary when a high air exchange ratio is needed during hot period.

Keywords: underground construction, natural ventilation, tunnel, chimney, hygrothermal behaviour.

1. Introduction

Soil is a good moderator of temperature. The great heat capacity and high thermal inertia allow a damping of aboveground temperature fluctuations at a rate exponential to the soil depth [1]. For that reason, from the dawn of civilization, human beings have exploited the underground space provided by natural or excavated caves for the purpose of habitation and as storage space for different agricultural produce [2].

Underground food storage is a common practice since pre-neolithic times in the Middle East (9000 to 7000 BC) and since Neolithic times in Europe [3]. It has been proven by historical, as well as modern precedents, that underground construction is a viable alternative to conventional design, because of the resulting lowering of energy use, especially in climates with harsh ambient conditions [4]. As well as to reduce the energy consumption, the temperature inside subterranean buildings is very stable, this can be useful in various industrial processes [5].As a result, there are some research works studying the energy efficiency and indoor thermal conditions of underground constructions, such as food cellars [5-9], cave dwelling [10] and earth-sheltered housing [4, 11].

Knowledge of surrounding soil temperatures is necessary to realize the energy conservation potential of underground buildings, although not sufficient. The temperature inside underground cellars is fundamentally conditioned by the undisturbed ground temperature and the outside air temperature which enters the cellars as a result of the ventilation[8]. The presence of ventilation chimneys greatly influences indoor conditions [9].

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In this research we analyze the natural ventilation in underground constructions, focusing on the entrance tunnel and ventilation chimney. We analyze how the differences between indoor and outdoor temperature influence natural ventilation during periods of high outside temperature.

2. Materials and Methods

To carry out the study, an underground construction used for food preservation has been selected, located in Spain. A monitoring system with 57 temperature and relative humidity sensors has been designed to analyze the natural ventilation and the behavior of the cave, tunnel and chimney. The sensors are distributed all over underground construction in order to detect changes in the indoor conditions and outdoor air infiltration. Monitoring process was carried out during the hottest months from June to October 2011.

2.1. Description of underground construction

The construction studied is in Spain, in a village in the province of Soria called San Esteban de Gormaz. This area has a continental Mediterranean climate, similar to the Mediterranean climate with regard to rainfall but with more extreme temperatures, similar to the continental climate.

The access to the underground construction is through a small hut partially buried composed by natural stone as external material. The door is of wood with permanently open ventilation holes in the upper part. Moreover, the lower cave is accessed through a vaulted tunnel of 8.3 m length and 11 m depth. The interior cave has an area of 80 m^2 and an average height of 2.4 m. There is a vertical ventilation chimney which communicates with the outside. It has a length of 9 m and a diameter of 0.5 m. Although the walls of the cave do not have any lining, the tunnel access is lined with stone and cement. The distribution of the underground construction studied is shown in Figure 1.

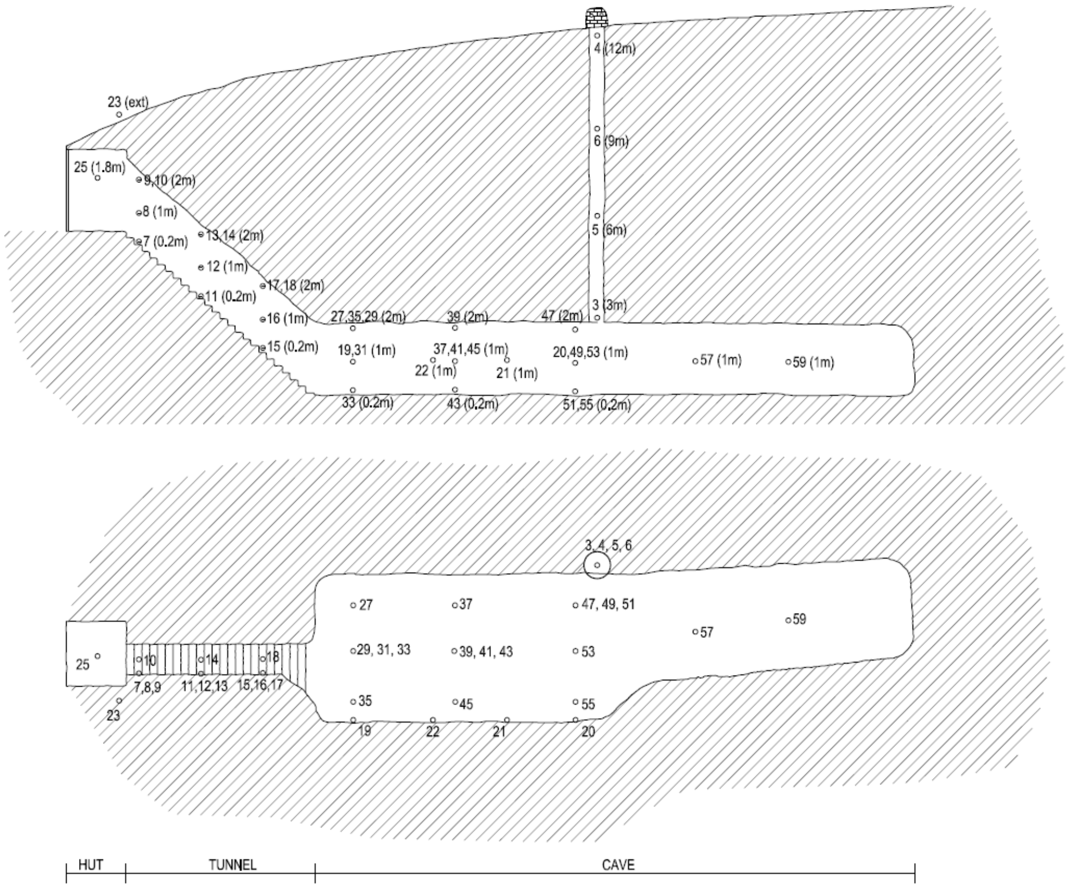

Fig. 1: Elevation and layout of the underground construction. Position and height of the sensors.

2.2. Monitoring the construction

We are only aware of few prior works that determine the number and placement of the sensors required to establish the indoor environment in an underground construction [12, 13]. In addition, there are no standards or guidelines to establish a monitoring plan in this type of construction. In the majority of existing studies regarding hygrothermal conditions or ventilation, sensor are situated in strategic locations without any criteria to ensure that the measures taken are representative. The working group has experience in monitoring underground constructions [7-9]. In this research, the sensors were placed regularly throughout the building with greater intensity in areas of high ventilation and lower thermal stability as the ventilation chimney or the entrance tunnel.

This study monitors in detail an underground construction, with all its areas (rooms, chimney and tunnel), in order to know the hygrothermal and ventilation behavior. To monitor the air temperature and air relative humidity inside the underground construction, the ground temperature and the outside air temperature, we used 57 temperature and humidity sensors: Hobo® Pro v2 temperature and relative humidity data logger (precision ±0.2 ºC in the range 0-50 ºC and ±2.5%rh from 10 to 90%; resolution 0.02 ºC at 25 ºC and 0.03% rh); Hobo® U12 four-channel external data loggers (±2mV ±2.5% of absolute reading); TMC50-HD, TMC20-HD, TMC6-HD temperature sensors (accuracy ±0.25 Cº a 20°C and resolution 0.03° a 20°C). Figure 1 shows the position of the sensors and the height (m) where they were located.

3. Results and discussions

The monitored construction presents a homogeneous and unchanged ambience inside the cave, despite the wide outside temperature fluctuations of the studied zone during the summer. Although the temperature sensors are distributed throughout the cave at different heights (0.2m, 1m and 2m), the average standard deviation of all of them is 0.1 °C, being 0.4 ºC the average of the maximum difference between two points in the cave. For relative humidity, the standard deviation is less than 1%.

The high stability inside the cave indicates a negligible influence on natural ventilation in summer, despite the permanently open vents in the doors and in the chimney. This phenomenon is explained by the combination of the main elements of the construction, such as the large volume of soil around the construction, the sloping tunnel access and the ventilation chimney. When the outside temperature is high, the design of these buildings reduces external fluctuations, with negligible effect on the inside ambience.

The ground thermal inertia maintains an inside temperature below the outside most of the time. The air temperature inside the cave equals the temperature of the adjacent ground, which given the great depth is almost constant. Thus, the difference between air temperature recorded in different parts of the cave at 1m high and the adjacent ground temperature registered in one of the walls at the same height is less than 0.1ºC during the summer. In addition, the relative humidity also presents great stability, due to poor ventilation and thermal stability, with values above 95% throughout the period.

The colder and heavier inside air hinders the entry of hot and light air from outside. The temperature of the walls of the tunnel varies with depth, becoming more stable due to the greater volume of soil above it. Therefore, the tunnel works as a regulator of temperature, dampening outside fluctuations which are very small at the end of the tunnel. Given the reduced ventilation, the air temperature in the tunnel is stratified according to the temperature of the surrounding ground (Fig. 2).

The ventilation chimney presents a dampening and stratification effect similar to the tunnel, but the variations are greater due to the lower section (Fig. 3). However, the scarce air flow detected in the final part of the chimney has no effect on the large volume of air in the cave.

At the end of the summer when the outside temperature can drop below the indoor temperature during the night, there is greater instability as a result of increased natural ventilation (Fig. 4). The temperature differences along the tunnel are reduced as the outside temperature decreases, reflecting a homogenization and mixing of the air. These differences become less than 2 °C, while in midsummer reached 8 °C. However, the night ventilation flow is not sufficient to alter the temperature or relative humidity of the cave.

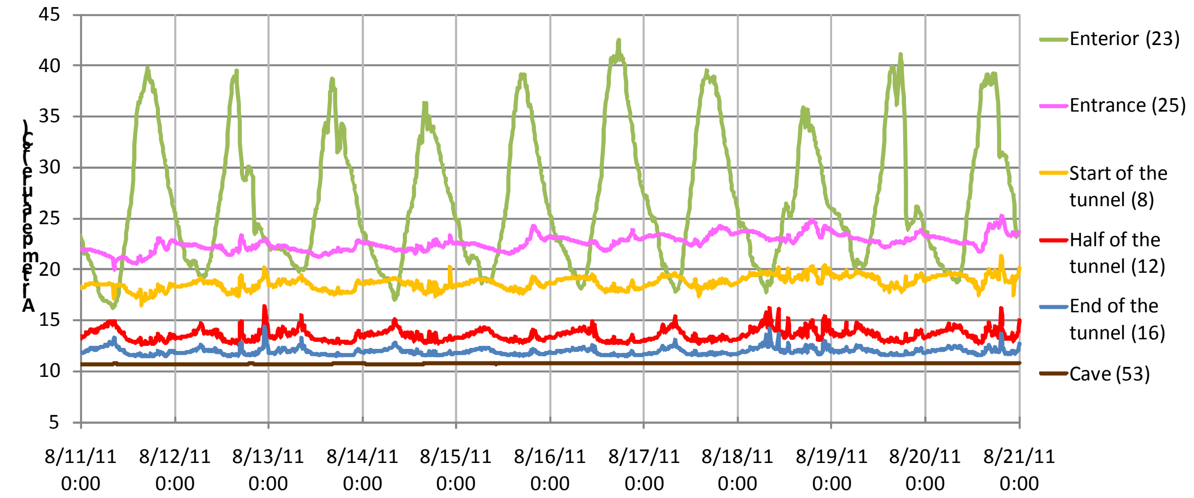

Fig. 2: Evolution of air temperatures inside the entrance, tunnel and cave, in the middle of August.

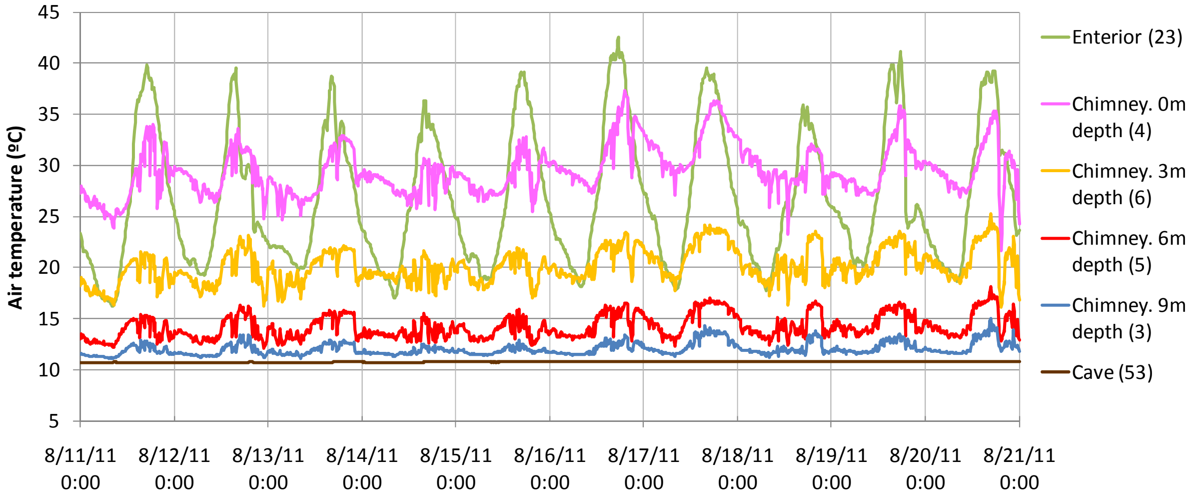

Fig. 3: Evolution of air temperatures inside the ventilation chimney and cave, in the middle of August.

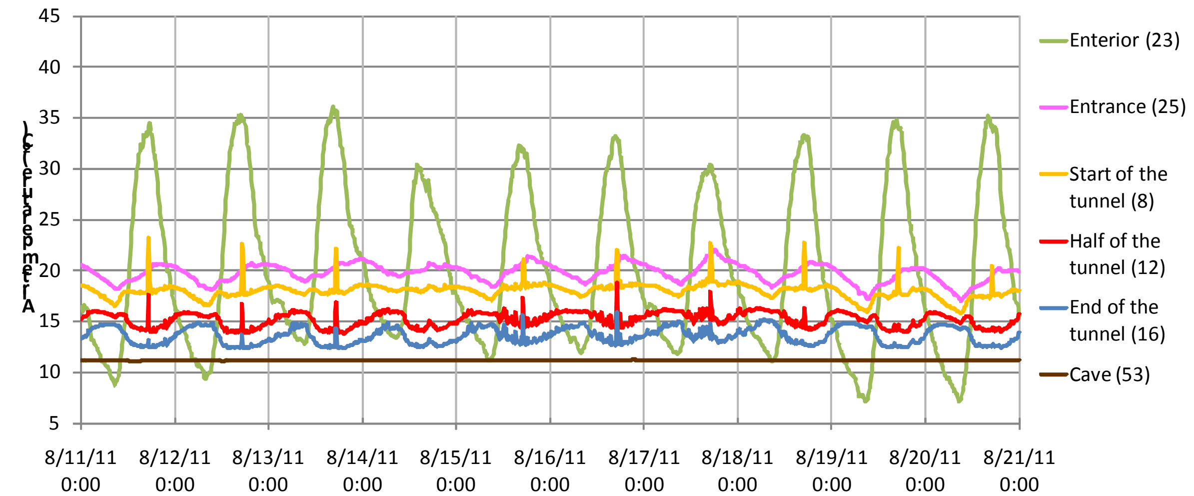

Fig. 4: Evolution of air temperatures in the entrance, tunnel and cave, at the end of the summer.

4. Conclusions

In hot-arid regions, it is essential to apply adequate environmental strategies in building design in order to minimize the interior cooling requirements[4]. Underground construction, with proper design, can have a great effect on reducing fluctuations in the external environment.

The ground thermal inertia, sloping tunnel access and ventilation chimney hinder natural ventilation in periods of high outside temperature. The ventilation flow is not sufficient to affect the temperature or relative humidity of the cave. Due to the scarce natural ventilation (even during the night), forced ventilation is necessary when a high air exchange ratio or lower relative humidity are needed during hot period.

5. Acknowledgements

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