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Annual evolution of the natural ventilation in an underground construction: Influence of the access tunnel and the ventilation chimney

Fernando R. Mazarrón [a,*], César Porras-Amores [b], Ignacio Cañas-Guerrero [b]

[a] Technical University of Madrid, ETSIA, Rural Engineering Department, 28040 Madrid, Spain
[b] Technical University of Madrid, ETSIA, Construction and Rural Roads Department, 28040 Madrid, Spain

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ABSTRACT

The knowledge of natural ventilation in underground constructions can help to optimize the design of their ventilation systems, reduce their energy consumption, and avoid the risk of accumulation of gases or toxics agents. This paper studies the natural ventilation in an underground construction throughout the year. The results show that natural ventilation is strongly conditioned by the existing gradient between the exterior and the interior temperature. The temperature of the interior walls evolves differently depending on the area and depth of construction. The access tunnel and the ventilation chimney, that is, the transition areas, are those which experience the highest changes in temperature, and play a key-role in the regulation of natural ventilation. For this reason, natural ventilation has large variations throughout the year. When the outdoor temperature is several degrees below the temperature of the transition areas, occurs a permanent entry of heavier cold air coming from the outside, which enter the cave through the lower area of the access tunnel. Simultaneously at the entrance of outside cold air in the underground construction, occurs the exit of the hottest air of the cave, via the highest area of the access tunnel, and the ventilation chimney. This phenomenon causes a homogenization of the temperature in the entire construction, despite the large distance that covers and the difference in depth of the different areas, which affect the ventilation in subsequent periods. On the contrary, when the outside temperature is higher than the inside temperature, the gradients of temperature along the access tunnel and the chimney hinder the entry of outside air. This causes a stagnation of the indoor air, heavier than the outside, which makes the indoor air to acclimate to the temperature of the walls at each point. In transition periods, during the day it is produced a similar behavior to the hot period and during the night it occurs a similar behavior to the cold period. However, there are differences in the period after the summer and in the period after the winter, due to differences in the temperature of the interior walls in each period.

1. Introduction

Ventilation plays a key-role in all kinds of underground constructions to replace the indoor air, and maintain a safe and productive environment. It has to be guaranteed that the users of the underground space can pass through it in a safe manner, which means that a proper renovation of the air has to be done to maintain air quality levels under the values permitted by the regulations of each country (Diego et al., 2011). The air flow is crucial to provide a comfortable environment but also to understand and control the spread of smoke or other toxic agents through the system (Pflitsch et al., 2012). Insufficient or malfunctioning ventilation inside, allows contaminated air to accumulate, and pollutant concentrations to increase. The accumulation of contaminants that comes primarily from inside the building, e.g. CO, can constitute a potential health hazard in micro-environments where people spend most of their time indoors (Papakonstantinou et al., 2003).

The air contribution from the outside has to be calculated in order to guarantee the fresh air presence in both standard operational circumstances and exceptional emergencies or accidents (Diego et al., 2011). Ventilation under emergency conditions such as different fire scenarios must ensure a rapid evacuation and efficient smoke management (Domingo et al., 2011).

The ventilation of an underground work must be, generally speaking, forced, both during the construction and during the use

* Corresponding author at: ETSIA, Avenida Complutense S/N, 28040 Madrid, Spain. Tel.: +34 913365670.
E-mail address: f.ruiz@upm.es (F.R. Mazarrón).

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of the installation once finalized (Diego et al., 2011). Because of its importance, the ventilation in different types of underground constructions has been widely studied, emphasizing studies in mines (Parra et al., 2006; Sasmito et al., 2013; Torano et al., 2009; Xu et al., 2013), in metro stations and networks (Kwon et al., 2010; Lin et al., 2008; Pflitsch et al., 2012), in parking (Chan et al., 1998; Chen, 2011; Papakonstantinou et al., 2003; Viegas, 2010), in storehouses (Stefopoulos and Damigos, 2007), etc.

However, in certain constructions, such as underground storehouses, natural ventilation has been used for centuries to maintain adequate conditions of conservation (Cañas and Mazarrón, 2009; Mazarrón and Cañas, 2009). Natural ventilation is being used since the time of the ancient Egyptians to ventilate underground constructions, taking advantage of the pressure difference produced by the falling of the external temperature during the night. The outside air temperature drops dramatically in the evening causing a cool air draught to flow into the excavations that flushed out the stale air and dust, and replaced it with fresh air, enabling the workers to continue working day after day (Gribble, 2009).

Previous studies have shown the existence of background air, independent of the current active ventilation systems in underground tunnels. Moreover this current does not consist of simple, continuous and equally distributed air movements; it is, on the contrary, a highly complex system of currents with spatial and temporal variations (Pflitsch et al., 2012). These studies highlight a complex system of air currents in the tunnels, influenced chiefly by the outside weather conditions. They also have shown that ventilation varies throughout the year, influenced by the differences in temperature between the outside and the inside. During the months of winter, when there is a high temperature gradient, the flow velocities with a stabilized flow direction are increased, establishing a strong chimney effect at most of the openings. On the contrary, during the months of summer, can result in flow reversals with weak velocities in the tunnels and limited exchanges with the outside (Pflitsch et al., 2012).

Studies in small constructions excavated below the surface show similar behavior. The temperature of the air in the interior cave is strongly conditioned by the undisturbed temperature of the ground at the average depth of the cave and by the temperature of the outside air. The inside temperature can be estimated thanks to the undisturbed temperature, introducing correction coefficients for the ventilation effect (Mazarrón and Cañas, 2008). The influence of outdoor air is increased in autumn and winter, while its effect is significantly reduced during spring and summer (Mazarrón and Cañas, 2009). On the other hand, studies also show that ventilation chimneys have a greater effect in colder months, and its effect is reduced in summer (Cañas and Mazarrón, 2009). However, these studies did not delve into the causes that motivate this behavior of the air neither analyze the role of the transition areas – the access tunnel and the ventilation chimneys – that usually generate these changes. Besides, the gradients of temperatures that occur are not studied.

The present study goes in depth into the analysis of natural ventilation in underground constructions of small size, simplifying the multiple variables that are involved in more complex structures. It is intended to use a simple construction to characterize in detail the behavior of natural ventilation throughout the year, and determine the role of transition areas-access tunnel and ventilation chimney. It is also aimed to highlight the importance of surface temperature gradients of the construction elements on ventilation. A good ventilation system should ensure that the regulatory limits are met throughout the underground construction whilst also providing with sufficient fresh air and keeping operating costs to a minimum (Sasmito et al., 2013). The knowledge of natural ventilation can help to optimize the design of the ventilation systems, reducing their costs and their energy consumption, and avoiding the risk of accumulation of gases or toxic agents. The results of this study could be useful when analyzing natural ventilation in more complex buildings.

2. Materials and methods

This study was carried out by selecting an underground construction of small size that allowed a comprehensive experimental study throughout a year. It is a traditional construction located in the center of Spain, used for more than a hundred years as a storehouse and as a meeting place where meals and celebrations are made (Fig. 1). To reduce the factors that could influence the ventilation, the building was not used as a meeting place during the monitoring phase. Only sporadic entries to it were made to get wine and other stored products.

The main hall or cave has an area of approximately 84 m^2, and is excavated to an average depth of more than 10 m (Fig. 2). Its section is not constant, presenting a wider area at the initial part and a lower section at the final part. The cave is accessed through a tunnel of vaulted section of 1 m wide, with 8.5 m long and angle of 65%. The construction presents a ventilation chimney on one side of the central area of the cave. Its section is approximately 1×0.5 m. Natural ventilation is allowed throughout the year through permanently open holes in the entrance and the chimney.

Fig. 1. Detail of the entrance, ventilation chimney, access tunnel and cave to the construction analyzed.