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Energy evaluation of rammed earth walls using long term in-situ measurements

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ABSTRACT

Available throughout the world and used in construction for thousand years, earthen materials are known to improve indoor air quality while keeping the internal temperature relatively stable. In Rhône-Alpes, France, the rammed earth technic is the most spread and consists in compacting layers of earth, one by one, within a framework. Current thermal standards, which are mainly based on thermal resistance of the material, urge to insulate walls. However, due to its interaction with its environment, and its couplings between heat and moisture transfers, the observed thermal behaviour of uninsulated rammed earth can be above the expectations. The objective of the paper is to highlight the living comfort provided by non-insulated rammed earth walls, for different orientations, from in-situ measurements performed over more than two years. Winter, with low energy use for heating, and summer, with no cooling device, are studied. The study points out the important role of solar irradiance on the thermal balance of the house, and thus the importance of a good architecture.

1. Introduction

Rammed earth, and more generally earthen materials, are often promoted as sustainable building materials, based on their low embodied energy (Morel et al., 2001; CRATerre and Houben, 2006). As a local material, it can be produced and used immediately on the construction site or nearby and does not require industrial processing. It is not a renewable but a reusable material; it requires no treatment to be reused and therefore has a very low impact in terms of embodied energy. However, rammed earth walls have a low thermal resistance (R-value), which makes them likely to provide poor thermal performance (Delsante, 2006; CSIRO, 2000). Indeed, high thermal resistance prevents heat loss from indoor space, and consequently less heating energy is needed to maintain constant indoor temperature, even for high outdoor temperature variations over days and seasons. During the summer, the aim is to prevent outdoor heat from entering as well as to expulse indoor heat to refresh the house during the night. On the other hand, to minimize energy consumption in winter, or more generally when the weather is cold, it is important not only to keep indoor heat but also to capture the maximum amount of outdoor heat during the day so that it can be used during the night when temperature drops. The passive use of solar energy for the heating of buildings is therefore becoming increasingly important and has been the subject of many studies since the work of Trombe (1974), Zrikem and Bilgen (1987), and Shen et al. (2007). Solar radiation is a time-dependent energy source which requires an energy storage being able to collect and store heat during the day and release it to indoor air when the temperature falls at night. As a consequence, this phenomenon decreases indoor temperature swings and improves the thermal comfort level (Stephan, 2014).

The thermal energy may be stored in the form of sensible heat in a massive material (Zhang et al., 2007). Another type of thermal storage system is based on the concept of latent heat storage through phase change materials (PCM) that are able to store more heat and whose melting temperature ranges from 20 °C to 32 °C (Tyagi and Buddhi, 2005; Goia et al., 2013). Indeed, they use chemical bonds to store and release heat when the material changes from solid to liquid and the other way round (Tyagi and Buddhi, 2005). More generally, many authors work on improving, by means of additional devices, the energy performance of buildings (Serra et al., 2010; Geros et al., 1999; Zalewski et al., 2012; Joulin et al., 2011). In this context, earthen materials, and rammed earth particularly, appear to be able to store both sensible heat as a massive material and latent heat due to liquid to vapour phase changes occurring within the pores. Several works (e.g. Taylor and Luther, 2004) support that the high thermal mass of the material avoids

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low temperatures in winter and hot temperatures in summer (Fernandez et al., 2005; Aste et al., 2009). When exposed to a heat source (internally with heater or externally with solar radiation), the wall absorbs and stores heat to release it when the surrounding temperature drops (Taylor and Luther, 2004). This effect may be enhanced by the so-called hygrothermal couplings between heat and mass transfers which occur within the earthen walls (Soudani et al., 2016).

The following study uses experimental data from a monitored house composed of non-insulated rammed-earth walls to investigate its energy performance over the seasons. In particular, the importance of solar exposure of the rammed earth walls is questioned for both winter and summer thermal performances. In order to explain these performances, the thermal behaviour of the wall, at material scale, is investigated. The aim is to identify parameters needed to evaluate accurately the thermal performance of the material.

2. Monitored house

2.1. Main characteristics of the house

The house studied in this paper is located in Saint-Antoine-l'Abbaye, in Isère, South-Eastern France. It has a living area of 150m2, over two floors, and a cold attics. Its envelope is composed of four non insulated load bearing walls in rammed earth, exposed to the South, East and West, and a timber-frame wall (mainly North orientation and upper parts of the construction), as it can be seen in Figs. 2 and 3.

The non-insulated rammed earth walls are 50 cm thick and 3 m high. They are constructed with a soil extracted from a village located at less than 6 km from the construction site. At material scale, various measurements were made, among which the particle size distribution, given in Fig. 1. It can be noticed that the soil includes around 10% of granulate with a diameter above 40 mm, typical of the houses of the area. The part below 2 μm gives the clay quantity, which reaches 16% for this material.

The manufacture gravimetric water content of the rammed earth was about 18%, and its average dry density, estimated on a test-wall realized before the house construction, was equal to 1.7. Before compaction, the soil was mixed with 2.5% of lime, which remains a low amount, in order to improve its resistance against water.

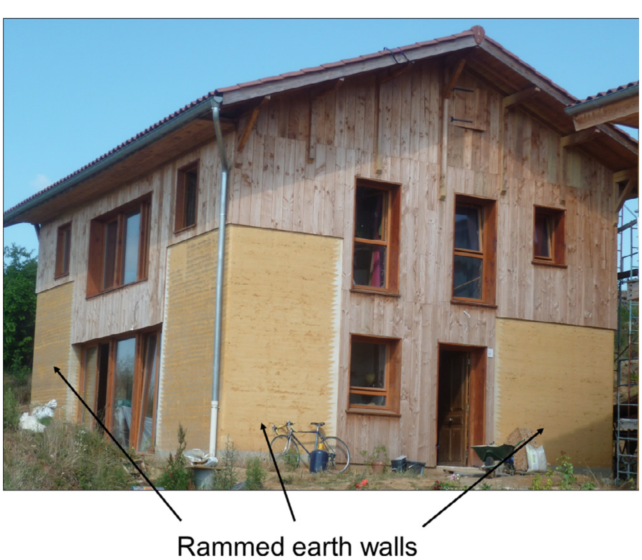

Fig. 1. House in Saint-Antoine-l'Abbaye (2014).

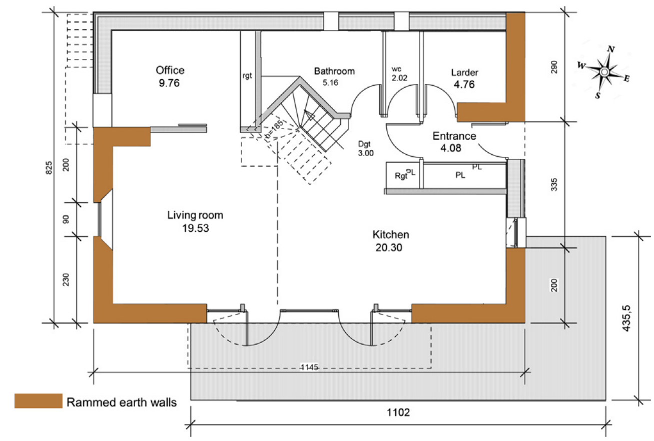

Fig. 2. Home plan for the ground floor, with the four rammed earth walls.

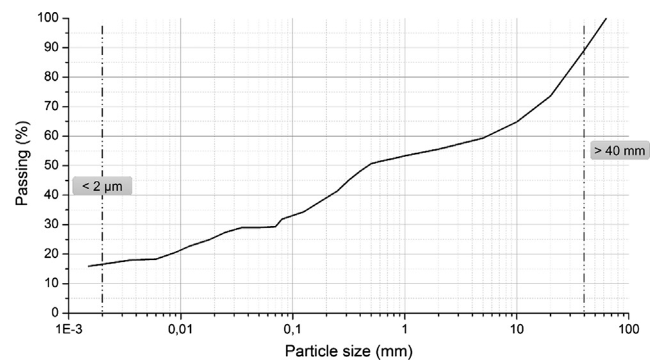

Fig. 3. Particle size distribution from Chabriac (2014).

The thermal conductivity was measured in laboratory on rammed earth blocks at different moisture content: it was equal to 2.4 W m^{-1} K^{-1} just after manufacture, to 2.1 W m^{-1} K^{-1} after a drying period of 48 h, and to 0.6 W m^{-1} K^{-1} when totally dried.

The timber-frame wall is filled with 34 cm of straw and coated with 6 cm of earth plaster and 2.5 cm of Douglas fir. The thermal transmittance of this highly insulated assembly is estimated at 0.13 W m^{-2} K^{-1}.

The slab is made out of a mix of cement, lime, straw, sawdust and cellulose wadding (commonly called GREB in France), and covered with fired earth tiles.

- Openings count windows and doors described below (according to Vodinh and Toulouse, 2015).
- Double glazing Argon for South, East and West facades (U = 1.70 W m^{-2} K^{-1}).
- Triple glazing Argon for North façade (U = 1.09 W m^{-2} K^{-1}).
- Double glazing for wooden French window (U = 2.95 W m^{-2} K^{-1}).
- Wooden door (U = 5.00 W m^{-2} K^{-1}).

The house is occupied by five persons (two adults and their three children from 10 to 18 years old). The heating system is a wooden stove operated by the occupants and located in the living room. Yearly energy use for heating is evaluated at two cubic meters of wood with the stove turned on two hours a day in winter, early spring and late autumn. This consumption corresponds approximately to 3000 kWh according to (ADEME, 2015), i.e. 20 kWh m^{-2} $year^{-1}$ (the surface being the living area). Given the size of the house, it indicates low energy use.