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Hygrothermal properties of earth bricks

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ABSTRACT

The comfort of the occupants and the quality of indoor air are becoming important parameters in the selection of building materials for use inside buildings. Earth is a material that seems to meet all the requirements, essentially because of its low environmental impact and its strong hygroscopic properties, as observed in historic earth constructions. The work presented in this paper aimed to measure the hygrothermal properties of five extruded earth bricks produced at five brickworks in the neighbourhood of Toulouse in southern France. The hygrothermal properties studied were vapour sorption isotherms, water vapour permeability, heat capacity, moisture-dependent thermal conductivity and effusivity. The mineralogical characterisation of the five earth bricks showed differences in the nature of the clay: the clay minerals contained in bricks 1–4 were montmorillonite, chlorite and illite whereas the only clay mineral contained in brick 5 was kaolinite. Despite this difference, the hygrothermal characteristics measured were very close in all five bricks and often close to the few data existing in the literature on earthen materials. The hygrothermal properties of the five earth bricks confirmed their capacity to regulate the relative humidity of indoor air.

1. Introduction

The impact of buildings on the environment is so great that construction techniques have been evolving significantly for several years. In France, for example, residential and commercial buildings were responsible for 44% of the final energy consumption in the country in 2011 according to the French ministry of ecology [1], sustainable development and energy. Several solutions have been implemented to reduce the impact of buildings on energy consumption and, more generally, on the environment. They include the use of materials that have little environmental impact and are more efficient from a thermal point of view. Along with these environmental concerns, occupant comfort and indoor air quality are also becoming important parameters in the selection of building materials for use inside buildings. Used since the birth of humanity as a natural building material alongside wood, earth is a material that seems to meet all the above requirements. In advanced economies, earth construction was abandoned in favour of concrete for several decades after the Second World War [2] but, nowadays, earth is again becoming attractive. The advantages of this material with respect to the new requirements outlined above are clear: the resource is available in large quantities, the energy required to extract, transform and produce materials in earth is extremely low and it is a totally recyclable material (in the case of earth bricks that are not chemically stabilised). In addition to these advantages, the main interest of this material certainly lies in the high thermal inertia that can be obtained, which could improve the comfort and thermal behaviour of continuously heated buildings [3], and in its strong hygroscopic properties, as observed in earth constructions left to us by previous generations. Transfers of moisture between air and earthen walls have two direct consequences for indoor air. Firstly, the earthen walls can regulate the relative humidity inside the building and the damping of humidity variation in buildings helps to increase indoor comfort. Secondly, according to the people living in earthen buildings, evaporation of the water contained within the earthen walls has a cooling effect in hot weather, so earth walls become natural air conditioners. While there are many studies on the mechanical properties of earthen materials (22 references (non-exhaustive list)) [4], not so many scientific studies have been published on the hygrothermal properties of these materials.

Among such studies, figures the work of Hall and Allinson on the hygrothermal behaviour of stabilised rammed earth, which is presented in three publications. The first deals with the effects of soil

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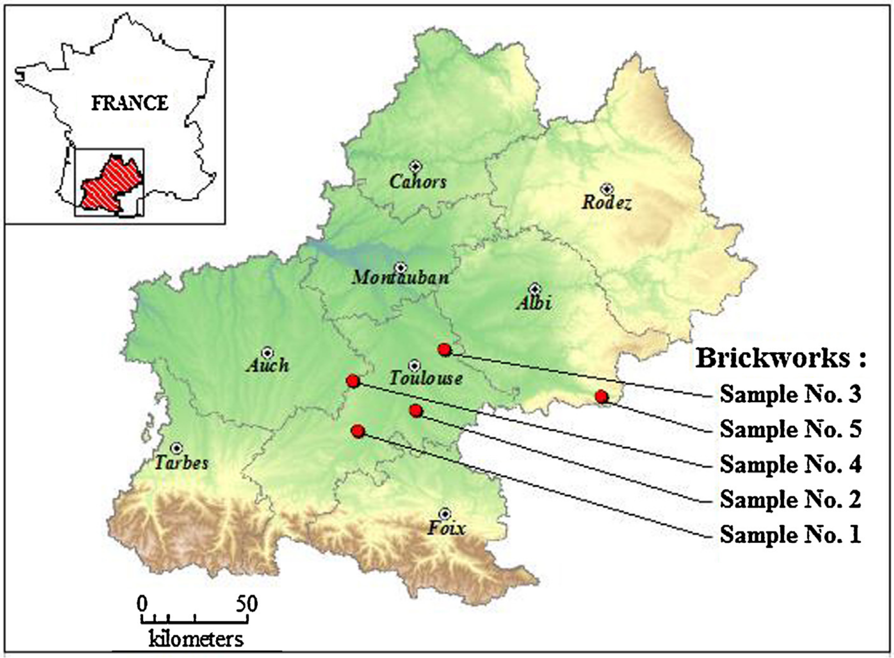

Fig. 1. Locations of the various brickworks.

grading on the moisture-content-dependent thermal conductivity of stabilised rammed earth materials [5] and the second is more dedicated to the hygrothermal functional properties of stabilised rammed earth materials [6]. A third paper presents the results of a study on the hygrothermal properties of a stabilised rammed earth test building in the UK [7].

Meukam et al. [8] worked on the thermophysical and mechanical characterisation of stabilised clay bricks in 2003 and, more recently (2010), Oti et al. [9] characterised stabilised unfired clay bricks, in particular from the thermal point of view. Goodhew and Griffiths [10] also worked on the thermal properties of earth walls. They measured the thermal conductivity and diffusivity of unfired clay bricks, a straw–clay mixture and straw bales using a thermal probe technique, with an iterative method for data analysis. Parra-Saldivar and Batty [11] presented results on the thermal behaviour of adobe constructions computed using dynamic thermal simulation software with synthetic weather data reproducing the climatic conditions of three regions at different latitudes in Mexico.

Some other studies have dealt with the hygrothermal properties of earth construction materials. For example, Tang et al. [12] studied the thermal conductivity of compacted bentonites and Liuzzi et al. [13] worked on the hygrothermal behaviour and moisture buffering effect of unfired, hydrated lime-stabilised clay composites in a Mediterranean climate. The latter publication is very interesting because the authors studied numerous hygrothermal properties: moisture-dependent thermal conductivity, moisture-dependent heat capacity, vapour sorption and water vapour permeability.

It is noteworthy that very few studies have investigated the hygrothermal properties of unstabilised earthen materials and, in particular, earth bricks. Moreover, such papers have essentially considered thermal properties and few have dealt with the hygrothermal aspect. Finally, in the last decade, numerous publications have studied rammed earth or compressed earth blocks but few report work on extruded bricks [14–17]. However, this manufacturing technique has some significant advantages: the extrusion process is very fast and permits large quantities of homogeneous (density, form and size) bricks to be produced.

The work presented in this paper aimed to measure the hygrothermal properties of five extruded earth bricks produced at five brickworks in the neighbourhood of Toulouse in southern France. The particular properties studied were vapour sorption isotherms, water vapour permeability, heat capacity, moisture-dependent thermal conductivity and effusivity. Except for the water vapour permeability (cup method), two different experimental methods were used for the measurement of each of these properties.

2. Materials and procedures

2.1. Materials

The five earth bricks under study came from five brickworks in the neighbourhood of Toulouse in southern France (Fig. 1).

These brickworks produced fired bricks and unfired earth bricks having different compositions, especially for the proportions of clay and sand in the mixtures. As shown in Fig. 1, all the brickworks were in the same area except for brickworks 5. The clayey soils of pits 1–4 had the same overall characteristics. Field studies and geological maps (not presented here) revealed that these soils were almost entirely silty clay with a few layers of marl and sandy lenses. The tints of these four soils were nearly the same. Clayey soil 5 was different from the other four because pit number 5 was on red clay ground.

The techniques for manufacturing bricks were the same in all the brickworks except for brickworks 4. For all brickworks, the soil, mixed with water to approximately its plastic limit, was placed in a vacuum extruder. In brickworks 1, 2, 3 and 5, the soil was pushed through a machined die by a rotating auger, producing a stiff column of clay that was subsequently cut into single bricks. In brickworks 4, the bricks were made differently. After the vacuum extruder, the earth was pressed into moulds by a large specific rotating auger. The surfaces of the moulds were covered with sand so that the bricks could be demoulded immediately, before their desiccation.

The dimensions of the bricks are summarised in Table 1.

To avoid having to cut dry samples in the earth bricks for the various tests, samples of different shapes were directly prepared in the brickworks at the outlet of the extruder, when the stiff