Building and Environment 82 (2014) 599–607

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

The moisture buffering capacity of unfired clay masonry

Fionn McGregor*, Andrew Heath, Andrew Shea, Mike Lawrence

BRE Centre for Innovative Construction Materials, Dept. of Architecture and Civil Engineering, University of Bath, UK

ARTICLE INFO

Article history:
Received 11 July 2014
Received in revised form
9 September 2014
Accepted 29 September 2014
Available online 8 October 2014

Keywords:
Unfired clay masonry
Compressed earth blocks
Moisture buffering
Clay plasters
Water vapour permeability
Sorption isotherms

ABSTRACT

In this paper, the results of static and dynamic hygric tests on 114 unfired clay masonry samples are presented. Samples were prepared as Compressed Earth Blocks (CEB) or plasters. The variability of soils, the soil density and the preparation methods were investigated to determine their influence on the moisture buffering capacity, water vapour permeability and sorption isotherms. The Moisture buffering Value (MBV) was measured according to the Nordtest protocol and the results could therefore be compared to conventional materials. The results indicate unfired clay masonry has a much higher potential to regulate the indoor humidity than conventional construction materials previously reported in the literature. Because of the benefits of humidity buffering, using unfired clay masonry could reduce health risk for inhabitants, reduce mould growth, reduce energy consumption of air conditioning and ventilation systems and increase the durability of building materials. The presented results show that the soil selection (mineralogy and particle size distribution) is more important for humidity buffering than changes than can be made to a particular soil (density, preparation methods or stabilisation) and the information presented will therefore allow designers to maximise the buffering capacity of buildings.

1. Introduction

The moisture buffering capacity of building materials is increasingly recognized for its beneficial influence on the indoor environment, which has associated benefits of material durability, occupant health and comfort [1] and also whole-building energy performance [2–6]. The potential to use building materials as an active agent to regulate indoor relative humidity (RH) and consequently to produce a healthier environment has been identified in historical buildings and is implemented in a number of contemporary projects, such as a rammed earth wall build by Martin Rauch in a Hospital in Feldkirchen, in Austria. It has been shown in previous studies that highly hygroscopic materials such as unfired clay have high potential to provide these functions in a building [6].

Specific research on the moisture buffering potential of unfired clay masonry was conducted in the early 90's in Germany under the supervision of Gernot Minke, by Lustig-Rössler [7]. A similar test was used for this study where some material properties were investigated but mainly surface treatments on soil blocks. At the Technical University of Denmark, Padfield [6] has compared different materials using an experimental flux chamber. The best performing materials to lower RH peaks were end grain wood and a mixture of Montmorillonite clay with perlite. Eshøj and Padfield [8] studied the humidity stabilising potential of porous materials from old buildings. More recently non peer reviewed reports were published in Germany by Eckermann and Ziegert [9] on the influence of unfired clay masonry on the interior room climate. Researchers in the UK have investigated the hygrothermal and moisture buffering performance of stabilised rammed earth walls [10,11]. In some cases the clay material was studied in combination with other materials such as organic waste [12] or fibrous materials such as hemp [13,14].

Most research focussing on moisture buffering investigates its overall influence on the hygrothermal performance of a building and how this can be simulated [3,4,15–23].

Other research focuses on the relations between static and dynamic hygric parameters involved in the buffering process through an inverse modelling approach [24] or through sorption kinetics [25]. The effect of boundary conditions on the measurement of hygric properties has also been investigated by several authors [26–29].

In this study we present the results of investigations to determine the moisture buffering capacity of a large range of unfired clay materials. Unfired clay materials are often locally sourced from subsoil and inherently sustainable because of the minimal processing and recyclability. These locally sourced materials can have a highly variable composition and this subsequently leads to a

* Corresponding author.
E-mail addresses: F.A.P.McGregor@bath.ac.uk, mcgregorfi@gmail.com (F. McGregor), a.heath@bath.ac.uk (A. Heath).

http://dx.doi.org/10.1016/j.buildenv.2014.09.027

variation in their structural and hygrothermal performance as building materials. This study aims to explore the variability of these materials and its influence on hygric behaviour. A fundamental understanding of the material properties which influence moisture buffering will enable material selection, modification and blending which can maximise this beneficial behaviour.

Hygric behaviour of unfired clay masonry was investigated through both dynamic and static tests. The dynamic moisture buffering was investigated following the method of the Nordtest project [2]. The weighing process was conducted outside of the climate chamber at set intervals rather than a continuous weighing inside of the chamber and this enabled multiple samples to be tested at the same time. A further investigation of the dynamic adsorption of water vapour was conducted using a DVS measuring system. The DVS system measures adsorption rates in detail over the relative humidity range. It gives indications on the dynamic process involved. A comparison was made between the moisture buffering test realised on large samples and the same test realised in the DVS on samples of less than 1 g.

Complementary static tests consisted of measuring the water vapour permeability and sorption isotherms as these hygric properties allow a more detailed characterisation of the material. The results obtained from static tests could also be compared to the dynamic behaviour of the materials. Trends observed through the comparison of the measurement of 114 samples are presented and discussed in this paper.

2. Materials

Samples were prepared with varying soil composition (particle size distribution, mineralogy), physical properties (apparent density which directly influences the pore size distribution) and with different manufacturing processes including variations in initial water content and mixing methods. In order to obtain variable material composition, natural and artificial soils were used. The natural soils were sourced in the UK from brick manufacturing companies, and one was sourced in France and provided by the ENTPE in Lyon, which has been used for the construction of a rammed earth house.

The brick soils from the UK were given codes (Gr, Ib, Al, Bi, Ch, Le and Th) rather than identifying the actual source because of the commercially sensitive information. The soil from France was named St.

To understand the influence of the nature of the clay minerals, artificially composed soils were prepared with a systematic variation of their clay mineralogy. Individual ingredients such as clay, silt and sand which compose natural soils were sourced and mixed in measured proportions. The clay minerals used where a 99% pure Kaolinite (Ka) sourced from IMERYS in Cornwall, a commercial bentonite (Be) based on Ca Montmorillonite and a commercial pillared Bentonite (pBe) based on the same Ca Montmorillonite. Both the natural and pillared Bentonites were sourced from OLMYX in France.

The pillared Bentonite consists of a momorillonite type clay with an artificially increased interlayer space by using a larger compatible cationic molecule. In this case the “pillars” are composed of proteins obtained from green algae. The pillared bentonite is produced and sold for its increased adsorption properties, mainly to control humidity in industrial pig farms.

The main composition of soils used is presented in Table 1.

A total of 24,100 mm ø test specimens of earth plasters were prepared from both UK and German suppliers. For each supplier, 12 samples, including three of a 12 mm undercoat, three of a 20 mm undercoat, three of 12 mm undercoat with 3 mm finishing coat and three of 20 mm with a 3 mm finishing coat.

Table 1
Composition of soils used.

Soils	Main clay mineralogy	Clay: <2 μm (%)	Silt: 2–63 μm (%)	Sand: 63 μm-2 mm (%)
Gr	Illite/Smectite	18	24	58
Ib	–	25	33.8	31.7
Al	Kaolinite, Illite/Mica	25.4	50	24.6
Bi	Kaolinite, Illite/Mica	50.1	39.5	10.5
Ch	Kaolinite, Illite/Mica	38.6	57.3	4.1
Le	Illite/Mica	14.8	66.7	17.2
St	–	16	10.3	26.3 (+44.4% gravels)-
Th	Kaolinite, Illite/Mica	5.5	25.1	25.4
Artificial soil 1	Kaolinite	20	20	60
Artificial soil 2	Kaolinite, Bentonite	25	20	55
Artificial soil 3	Kaolinite, Bentonite and Pillared Bentonite	25	20	55
Plaster 1	–	10 (clay + silt)		84 (+6% gravels)
Plaster 2	–	1.4 (clay + silt)		96.6 (+2% gravels)

The exact nature of additives and mineralogical composition of the plasters was not provided by the manufactures. The materials were mixed with water and stabilisers (if required and identified in Table 2) and then compressed in a mould using a hydraulic ram to obtain the desired density for both the unstabilised compressed earth blocks (CEB) and stabilised compressed earth blocks (CEBS). The plaster samples were placed in a mould in a single layer at the manufacturer recommended water content using a plastering trowel.

CEB samples were prepared as discs of 100 mm in diameter and 30 mm in thickness with a density of approximately 1800 kg/m^3. Due to variable shrinkage behaviour of the material variations in size (+/− 4%) and density (+/−10%) were observed. Therefore three replicates were prepared for each soil mix to limit experimental error. A sample is shown in Fig. 1, it also shows how the aluminium tape was used to seal all faces except one so that only this face of the sample is exposed to the relative humidity variation. Table 2 presents the different groups of samples tested. In total 114 samples were tested and the results for each group are aggregated for clarity of presentation. For comparison, Fig. 2 incorporates the results of Lustig-Rossler [7] who performed some initial research on the hygric behaviour of unfired clay masonry.

3. Testing methodology

3.1. Water vapour permeability

Water vapour permeability was tested in accordance with the ISO 12572:2001 (ISO, 2001) standard; using the wet cup method.

Table 2
Overview of sample groups and properties investigated.

Group	Type	Soils used	Modified parameters	Number of samples
I	SCEB	Gr	Addition of stabiliser	18
II	CEB	Gr	Initial water content	9
III	CEB	Ib	Initial water content	9
IV	CEB	Artificial 1	Apparent density	9
V	CEB	Artificial 2	Mixing method	9
VI	CEB	Artificial soil 3	Bentonite/Pillared Bentonite content	18
VII	CEB	Al, Bi, Ch, Le, Th and St	Mineralogy, particle size distribution	18
VIII	Plaster	Plaster 1	Thickness and finishing coat	12
IX	Plaster	Plaster 2	Thickness and finishing coat	12
X	Results of Lustig-Rossler [7]			