# Improving the hygrothermal properties of clay plasters

A. Thomson[1,a], D. Maskell[1,b], P. Walker[1,c], M. Lemke[2,d], A. Shea[1, e], M. Lawrence[1, f]

[1]BRE Centre for Innovative Construction Materials, University of Bath, Bath, UK

[2]Claytec, Viersen, Germany

[a]A.J.Thomson@bath.ac.uk, [b]D.Maskell@bath.ac.uk, [c]P.Walker@bath.ac.uk,

[d]M.Lemke@claytec.com, [e]A.Shea@bath.ac.uk, [f]M.Lawrence@bath.ac.uk

**Keywords:** Clay, Hygroscopic, Thermal Conductivity, Specific heat capacity, Moisture buffering.

**Abstract.** The requirement to reduce operational energy use in the built environment has driven a rise in the level of building envelope airtightness. An unintentional consequence of this can be a reduction in the indoor environment quality with respect to hygrothermal comfort. Some aspects of this may be addressed through correctly commissioned active ventilation systems. However, there is also a need to consider the passive role that building materials have in maximising the quality of the indoor environment.

There has been growing interest in the use of exposed clay surfaces for the passive regulation of indoor temperature and humidity levels. This is largely due to the exposed thermal mass and hygroscopic properties that help buffer the temperature and relative humidity of the internal environment. There is also scope for the inclusion of mineral and organic aggregates to help improve these hygrothermal properties.

This paper presents results from preliminary testing on a range of novel clay coatings, which incorporate different mineral and organic aggregate contents. Two novel mixes were prepared with an enhanced level of mineral and organic aggregate exchange. Both mixes showed a reduction in thermal conductivity compared to control clay mixes. The moisture buffering of the plaster was improved by the increased organic aggregate content while no significant change was observed for the mineral aggregates. The results of this paper will inform future developments of clay plasters, which will support the development of airtight buildings with improved indoor environment quality.

## Introduction

Clay wall coatings are increasingly used within buildings due to increased consumer interest in sustainable construction and improved indoor environment quality. The large surface area of plastered walls and their exposure to the internal climate offers significant potential to passively assist in the regulation of the internal environment for improved occupant wellbeing. The focus of research in this area has therefore been to identify and enhance the best performing wall plasters in terms of thermal conductivity and moisture buffering properties.

It is widely acknowledged that the exposed thermal mass of a building's internal envelope is able to buffer large variations in temperature. However, for some materials there is also a significant moisture buffering effect that is less well-known within the construction industry. This buffering effect is provided by hygric mass, referred to as the vapour, or moisture, absorption capacity of a material, capable of buffering humidity variations inside a room. This is especially relevant for rooms where, at times, the rate of moisture generation (due to human activity) does not balance with the rate of moisture extraction (by way of ventilation).

In addition to the energy performance and durability of the building envelope, one of the most significant factors within the indoor environment is the relative humidity of the air (RH), which influences the comfort of occupants and the indoor air quality (IAQ). A steady indoor environment, with a small range of temperature and relative humidity variation will provide the most comfortable climate for its occupants. The optimum levels of relative humidity are between 40% and 60%, with levels outside of this optimum range associated with discomfort, health risks and degradation of a building [1]. Relative humidity levels above 60% can lead to condensation within a building, resulting in the growth of microorganisms whilst relative humidity levels below 40% are associated with discomfort and respiratory conditions [2][3][4].

A number of studies have demonstrated that interior moisture buffering by the building fabric can beneficially affect energy consumption, component durability, thermal comfort and air quality [5][6][7]. Padfield [8] demonstrated the enhanced moisture buffering potential of clay based materials compared to many other conventional materials. However, there is still a need for wider recognition of these effects and scientific characterisation of materials. Additionally, there is a growing interest in using aggregates to improve the humidity buffering properties of coating plasters.

This paper presents the findings from a study that investigated the influence of novel aggregate additions to clay coatings to enhance their hygrothermal properties. Thermal conductivity and moisture buffering potential were the focus of the testing, as these give a clear indication of the potential improvements in the regulation of temperature and relative humidity of an internal environment. These properties have the potential to be improved through the inclusion of aggregates that either change the pore structure of the coating or actively participate in the internal environment regulation.

## Materials and methods

Two novel clay coating mixtures were developed with a focus on improving thermal conductivity and moisture buffering potential. These novel coatings are compared to standard base and top coat mixes used in industry. In Germany the common definition of clay plasters and mortars, as set out in DIN 18947, provided the basis for this work [9]. DIN 18947 allows for flexibility in the use of novel aggregate additions as described below.

Mineral aggregates permitted to be used in clay plasters:

- all natural grains of sand and gravel;
- brick-dust; untreated/non-processed, without mortar;
- natural lightweight filler e.g. perlite, expanded clay, natural pumice.

Organic aggregates permitted to be used in clay plasters:

- all plant parts and plant fibres;
- animal hair;
- chipped or cut wood; untreated, no processed wood-based products (eg MDF).

For this study aggregates were incorporated into a natural earthen clay. The introduction of novel aggregates requires an effective substitution, not an addition, to be made so that the grain curve or sieving line of the earthen clay is not significantly altered.

**Materials.** The research presented in this paper focused on testing four different clay plasters.

Two of the plasters are standard benchmark mixes that are widely used as base and top coat plasters (Figure 1). The other two plasters were developed with the specific aim of improving the hygrothermal properties through substitution of bio-based and mineral aggregates (Figure 2).

The structure and grain curve of the natural earthen clay used for the novel mixtures consists of 10.4% clay, 87.3% silt and 2.3% sand (mostly fine grain). This type of natural earthen clay is usually sufficient for final fine clay mixtures like plasters. The two novel aggregates selected as part of this investigation are described below.

The first aggregate to be exchanged into the natural clay mix was natural pumice, which acts as a lightweight filler to the earthen clay. Natural pumice reduces the density of the mixture. In the final mix pumice was added to the earthen clay up to 35% by mass with grain sizes from 0.5mm to 2mm. For workability, cellulose fibres and methylcellulose were also added at less than 1% by mass and sand was added to adjust the grain curve.

The second aggregate to be exchanged was hemp shiv and fibres, which were added to the natural clay mix up to a maximum of 10% by mass. The hemp shiv used in this mix was a co-product from the production of hemp insulation. This hemp shiv was used because it carries some hemp fibres into the mixture. For workability, cellulose fibres and methylcellulose were also added at less than 1.5% by mass and sand was added to adjust the grain curve.

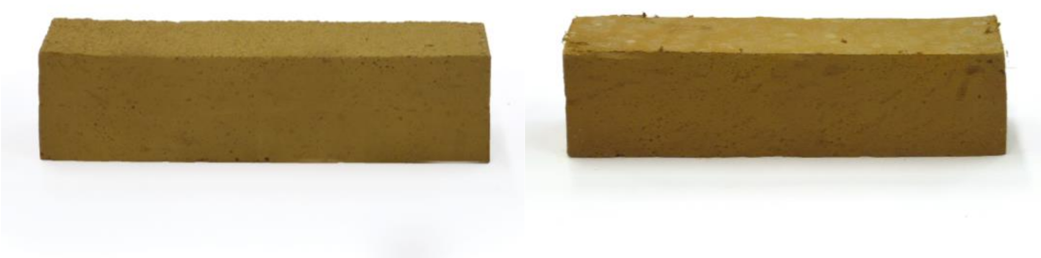

Figure 1. Base coat (left) and top coat (right) clay coating specimens

Figure 2. Novel clay coatings with pumice (left) and hemp (right) aggregates

For reference the novel mixes shall be termed ‘Pumice’ and ‘Hemp’ whilst the two standard mixes will be termed ‘Top coat’ and ‘Base coat’. The top coat plaster is a clay, sand and flax fibre mix and the base coat plaster is a clay and sand and mix.

**Moisture buffering test method.** Moisture buffering properties were determined in accordance with ISO 24353:2008 [10]. The cyclic test method for middle humidity level was adopted. This method required specimens to be pre-conditioned at a relative humidity of 63% and a temperature of 23°C before cyclic climatic variations were started. Four cycles of the following conditions were run whilst the mass of the specimen was logged:

- Step 1: 12h, relative humidity of 75% and temperature of 23°C;
- Step 2: 12 h, relative humidity of 50% and temperature of 23°C.

Specimens were tested using environmental chambers programmed to subject the specimens to the humidity cycles set out above. Mass balances installed inside the chambers were used to record specimen mass at 5 minute intervals. A screen was placed around the mass balance to minimize the influence of air movement over the surface of the specimens during testing. An anemometer was used to measure wind speed at the specimen surface and was found to be an average of 0.1 m/s.

Specimens were prepared in phenolic plywood moulds to the following dimensions; 150 x 150 x 20 mm thick. In all instances the specimens were a minimum of 28 days old at the time of testing. Aluminium tape was used to seal the back and sides of the specimens to ensure vapour exchange only occurred through a single face of the material (Figure 3). Fourth cycle moisture adsorption and desorption content values and rates were calculated in accordance with Section 8.3 of ISO 24353:2008.

Figure 3. Clay moisture buffering specimen

**Thermal conductivity test method.** The thermal conductivity of the two novel clay coatings was measured using a heat flow meter apparatus following ISO 8301:1991 [11]. As with the moisture buffering specimens, 400 x 400 x 25 mm thick thermal conductivity specimens were prepared in phenolic plywood moulds. The thermal conductivity of the two standard clay coatings was measured according to DIN 18947 [9].

**Physical and mechanical properties.** The bulk density of the hardened mixes were determined in ambient conditions following EN 1015-10 [12]. The flexural and compressive strength was determined in accordance with EN 1015-11 [13]. Specimens were loaded under displacement control at a rate of 0.2 mm/min and 0.5mm/min for the determination of flexural and compressive strength respectively.

## Results and discussion

**Moisture buffering results**. The moisture buffering properties of the coatings were determined using the methods set out above. Three specimens of each coating type were tested and mean average results are presented with coefficient of variation values in Table 1. For reference, results from testing gypsum specimens are also included in Table 1. The data is shown graphically in Figure 4. Mean average hourly rates of fourth cycle adsorption/desorption are presented in Figure 5 for the four clay types.

Table 1 Moisture buffering properties of clay composite coatings (COV%)

| Specimen | Moisture adsorption content for 4th cycle (kg/m$^2$) | Moisture desorption content for 4th cycle (kg/m$^2$) |
|---|---|---|
| Base coat | 0.035 (10.3%) | 0.035 (8.8%) |
| Top coat | 0.045 (9.8%) | 0.044 (13.9%) |
| Pumice | 0.043 (3.3%) | 0.045 (3.2%) |
| Hemp | 0.054 (2.1%) | 0.055 (2.4%) |
| Gypsum | 0.014 (4.9%) | 0.013 (7.3%) |

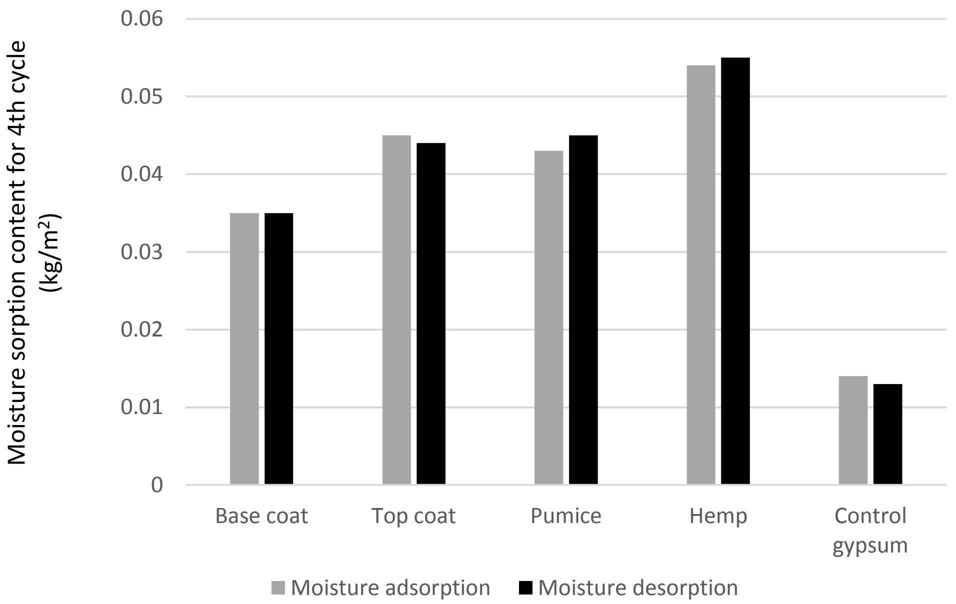


Figure 4. Moisture adsorption/desorption capacity of plaster specimens

The results of the moisture buffering tests show that the introduction of novel plant and mineral aggregates has a positive effect on the capacity for clay plasters to adsorb and desorb water vapour. The use of hemp shiv and fibres yielded a moisture buffering capacity 54% greater than that for the reference base-coat plaster. The use of pumice aggregate also gave a higher performance when compared to the standard base-coat plaster. However, unlike the hemp mix the pumice mix showed an almost equal level of performance with the standard top coat plaster. This may, in part, be attributed to the incorporation of flax fibres and higher proportion of fines in the top-coat plaster. The comparison of the moisture buffering capacity of clay plasters with gypsum highlights the potential for improved humidity control within a building. Clay plasters offer two to three times the vapour adsorption/desorption capacity of the same thickness of gypsum plaster.

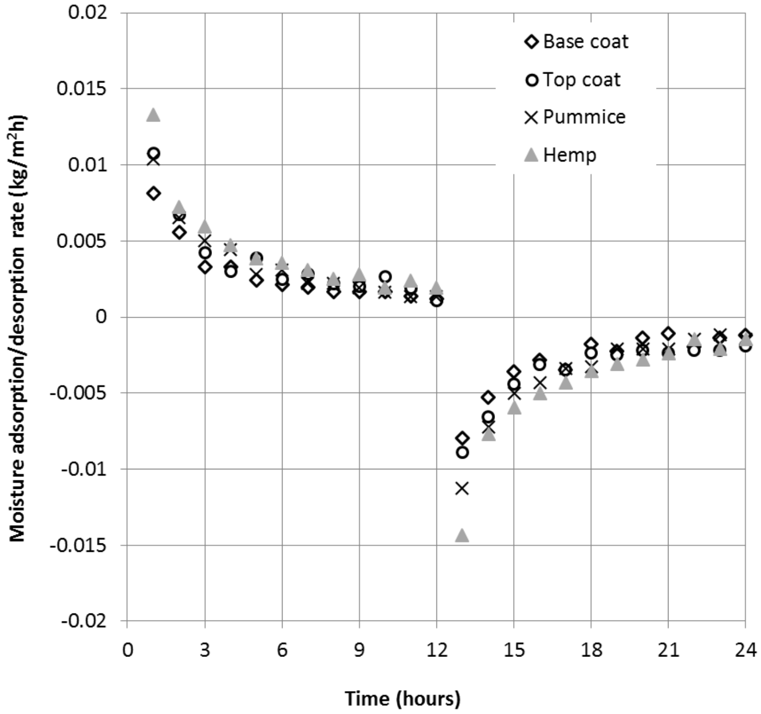


Figure 5. Moisture adsorption/desorption rate of clay coatings

The rate of moisture adsorption and desorption is an important property to consider if an internal coating plaster is to be effective. A plaster that is relatively slow to respond to changes in humidity levels will not be able to buffer short term peaks even if it has the capacity to store a large amount of water vapour. The use of hemp shiv and fibre aggregates in clay plaster was found to significantly increase the initial rate of moisture adsorption and desorption when compared to the standard clay mixes. Both adsorption and desorption rates were over 60% higher than for the standard base coat plaster. This suggests that the use of hemp aggregate would be well suited to environments where there are short intense peaks in internal humidity, which would not adversely affect the integrity of the hemp.

**Thermal conductivity results**. The incorporation of pumice and hemp aggregates into clay plasters improves the moisture buffering capacity. Another intentional effect of incorporating these aggregates was a reduction in the bulk density of the plaster. This reduction in density yielded significant improvements in the thermal insulation properties of the plaster specimens when compared to the reference base and top coat materials (Table 2).

**Table 2 Thermal properties of clay composite coatings**

| Specimen | Thermal conductivity (W/mK) |
|---|---|
| Base coat | 1.1 |
| Top coat | 0.9 |
| Pumice | 0.1 |
| Hemp | 0.1 |

Figure 6 presents thermal conductivity results for the four clay plasters plotted against bulk density. The incorporation of the pumice and hemp aggregates reduced the density of the plasters by between 43-56% when compared to the base coat plaster. As a result of this reduced density, thermal conductivity was reduced by 87-89% when compared to the base coat plaster. This is a very encouraging result when considering the contribution this reduction in density can make in terms of energy conservation in use and in the transportation of the material.

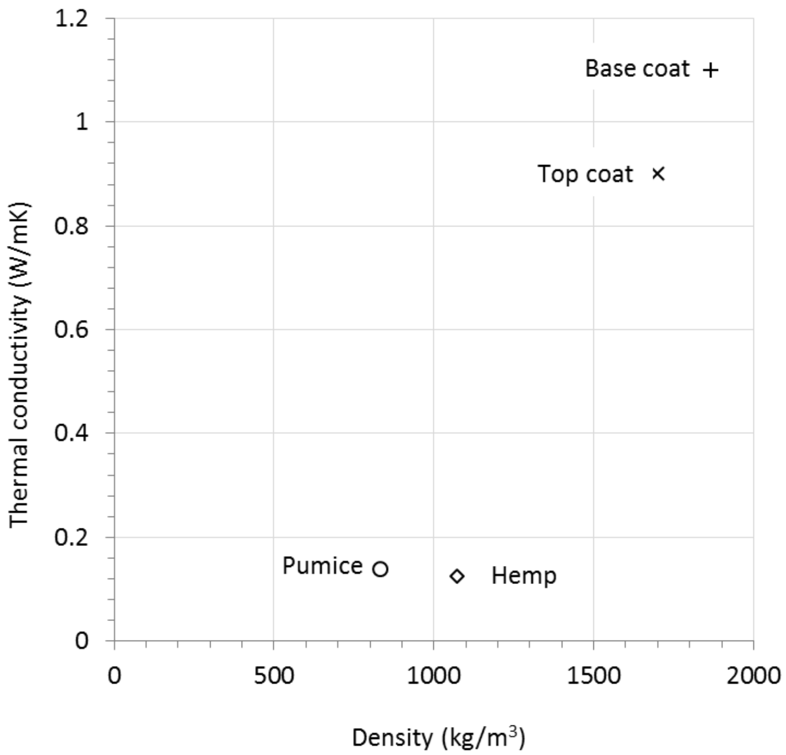

Figure 6. Thermal conductivity plotted against density of clay coatings

**Mechanical properties.** Reducing the density of the coatings inevitably has an impact on their mechanical properties. For reference mechanical properties of the coatings are presented in Table 3. Whilst a reduction in both the flexural and compressive strength were observed, the reduction is not anticipated to significantly restrict the use of the new materials as plasters.

**Table 3 Mechanical properties of clay composite coatings**

| | Density [kg/m$^3$] | Flexural Strength [N/mm$^2$] | Compressive strength [N/mm$^2$] |
|---|---|---|---|
| Base coat | 1867 | 0.97 | 2.60 |
| Top coat | 1699 | 1.19 | 2.86 |
| Pumice | 831 | 0.77 | 1.79 |
| Hemp | 1074 | 0.66 | 1.38 |

**Summary and conclusions**

The incorporation of mineral (pumice) and bio (hemp) aggregates into clay plasters can significantly improve the hygrothermal properties when compared to standard clay products. However, these improvements are to be balanced with reduced mechanical properties. Significant improvements of over 80% were observed for the thermal conductivity of clay plasters, which incorporated pumice and hemp aggregates when compared to a standard clay base coat plaster. The capacity of clay plasters to buffer moisture was also seen to improve when pumice and hemp aggregates were incorporated. Of particular note was that the use of hemp aggregates significantly increased the initial rate of moisture adsorption and desorption when compared to the standard clay mixes. Both adsorption and desorption rates were over 60% higher than for the standard base coat plaster.

**Acknowledgements**

The work presented in this paper has received funding as part of the ECO-SEE project from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 609234. The authors would like to thank Claytec for their support in providing materials in kind.

**References**

[1] Sterling, E. M., Arundel, A., and Sterling, T. D. (1985). Criteria for human exposure to humidity in occupied buildings. *ASHRAE transactions*, *91*(1B), 611-622.
[2] Fang, L., Clausen, G., & Fanger, P. O. (1998). Impact of temperature and humidity on the perception of indoor air quality. *Indoor air*, *8*(2), 80-90.
[3] Toftum, J., Jørgensen, A. S., & Fanger, P. O. (1998). Upper limits of air humidity for preventing warm respiratory discomfort. *Energy and Buildings*, *28*(1), 15-23.
[4] Lucas, F., Adelard, L., Garde, F., & Boyer, H. (2002). Study of moisture in buildings for hot humid climates. *Energy and Buildings*, *34*(4), 345-355.
[5]Janssen, H and Roels, S (2009). Qualitative and quantitative assessment of interior moisture buffering by enclosures. *Energy and Buildings,* 41(4), 382-394.
[6] Woloszyn, M., Kalamees, T., Olivier Abadie, M., Steeman, M. and Sasic Kalagasidis, A. (2009) The effect of combining a relative humidity sensitive ventilation system with the moisture buffering capacity of materials on indoor climate and energy efficiency of buildings. *Building and Environment*, 44, 515–524.
[7] Osanyintola, O., Simonson, C., (2006) Moisture buffering capacity of hygroscopic building materials: Experimental facilities and energy impact. *Energy and Buildings,* 38, 1270–1282.
[8] Padfield, T. (1998) The role of absorbent building materials in moderating changes of relative humidity. *PhD Thesis*, Department of Structural Engineering and Materials, Lyngby, Technical University of Denmark, 150.
[9] DIN 18947: 2013 Earth plasters - Terms and definitions, requirements, test methods.
[10] ISO 24353:2008 Hygrothermal performance of building materials and products - Determination of moisture adsorption/desorption properties in response to humidity variation. International Standardization Organization (ISO).
[11] ISO 8301:1991. Thermal insulation - Determination of steady-state thermal resistance and related properties - Heat flow meter apparatus. International Standardization Organization (ISO).
[12] EN 1015-10:1999 Methods of test for mortar for masonry. *Determination of dry bulk density of hardened mortar.* London: BSI.
[13] EN 1015-11:1999 Methods of test for mortar for masonry. *Determination of flexural and compressive strength of hardened mortar.* London: BSI