The moisture buffering capacity of unfired clay masonry

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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.

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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-Rüssler [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. Eschøj 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 indoor 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
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 OLMVX in France.

The pillared Bentonite consists of a montmorillonite 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 mm² 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.

The exact nature of additives and mineralogical composition of the plasters was not provided by the manufacturers. 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/m³. 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>
<thead>
<tr>
<th>Table 1</th>
<th>Composition of soils used.</th>
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<tr>
<td>Soils</td>
<td>Main clay mineralogy</td>
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<tr>
<td>Gr</td>
<td>Illite/Smectite</td>
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<tr>
<td>Ib</td>
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<td>Al</td>
<td>Kaolinite, Illite/Mica</td>
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<td>Th</td>
<td>Kaolinite, Illite/Mica</td>
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<tr>
<td>Artificial soil 1</td>
<td>Kaolinite</td>
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<tr>
<td>Artificial soil 2</td>
<td>Kaolinite, Bentonite</td>
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<tr>
<td>Artificial soil 3</td>
<td>Kaolinite, Bentonite and Pillared Bentonite</td>
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<td>Plaster 1</td>
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<td>Plaster 2</td>
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<table>
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<th>Table 2</th>
<th>Overview of sample groups and properties investigated.</th>
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<tr>
<td>Group</td>
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<td>I</td>
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<tr>
<td>II</td>
<td>CEB</td>
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<tr>
<td>III</td>
<td>CEB</td>
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<td>IV</td>
<td>CEB</td>
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<td>V</td>
<td>CEB</td>
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<td>VII</td>
<td>CEB</td>
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<td>VIII</td>
<td>Plaster</td>
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<td>IX</td>
<td>Plaster</td>
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<tr>
<td>X</td>
<td>Results</td>
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The sample was sealed to the top of a plastic container which contained a saturated salt solution of potassium nitrate to maintain a RH level of 94%. The container was then stored in a TAS (Temperature Applied Science Ltd) environmental chamber maintained at 50% RH and 23°C. To provide a vapour-tight seal around the samples, aluminium tape was used as this has provided suitable performance in previous tests [4]. Additionally, a thin bed of silicone was applied to seal the sample to the plastic cup. The water vapour resistance factor (μ) corresponds to the ratio of the water vapour permeability of the sample over the water vapour permeability of air [30]. The water vapour resistance factor has no unit; a water vapour resistance factor of 10 corresponds to a material that has a 10 times greater resistance to water vapour diffusion than air has in the same conditions. This factor is commonly used in different laboratories [31].

All measurements including the moisture buffering test were done in the same climate chamber. Air velocity measurements taken in the chamber using a hot wire anemometer indicate an average air velocity of 0.65 m/s.

The weighed variance of the water vapour resistance obtained from 41 sets containing each 3 identical samples is 0.26. This means the water vapour resistance factor measured varies within a set of three identical samples by only 0.26 points. This is considered a good accuracy for a test that is subject to much experimental variability such as the atmospheric pressure, RH and temperature fluctuations or vibration noises affecting the scale. The calculated standard error varied between 0.01 and 0.55 for all sets of three identical samples. The testing conditions were kept as constant as possible during the study.

3.2. Dynamic vapour sorption

A dynamic vapour sorption (DVS) system was used to determine sorption isotherms at 23°C of 21 samples. The time necessary to measure one single sample is around ten days. Therefore only specifically selected samples were measured using this method to understand, for example, the influence of the density on the sorption isotherm of the soil. The moisture capacity corresponds to the slope of the sorption isotherm, it is the term used to describe the storage capacity difference of the sample between two RH levels. It is not to be confused with moisture buffering capacity which is used to describe the dynamic moisture adsorption.

The following assumptions were made for the measurement of sorption isotherms:

(i) For a hygroscopic material with particle size smaller than 2 mm and a homogenous distribution, a sample of less than 1 g is representative of the adsorption process on the particles.
(ii) The precision of the instrument makes the repetition for each sample as with the MB test and water vapour permeability test unnecessary.
(iii) The adsorption at very high RH (above 90%) may be underestimated because total equilibrium could not be reached in the specified maximum time allocated, but this is not considered a problem as these high humidity levels are unlikely to be achieved for an extended period in a real building. This is expected to slightly reduce the hysteresis.

The same test procedure as in a previous paper was followed [27]. Each step in RH during the DVS measurement is incremented either when a stable mass is achieved with less than 0.0001% mass change per minute or a maximum time interval of 360 min is reached.

The information provided by the DVS on the dynamic adsorption to reach equilibrium in between each humidity step is presented and discussed in a later section. The DVS was also used to replicate the moisture buffering test with RH levels from 50% to 85% RH to compare the results obtained from samples under 1 g with full scale moisture buffering test although in this test the RH was allowed to change when a steady state was reached.

The experimental error in measuring sorption isotherms is greatly reduced when using the DVS, the scale has an accuracy of ± 0.1 μg, the temperature can be maintained to ± 0.1°C and the RH is maintained to ± 1% RH.

3.3. Moisture buffering

The moisture buffering test, used the step-response method. This method records the mass variation during RH cycles of a specimen with a known exposed surface area. There are various test protocols currently in use [2,32,33] and all use the same principle of exposing samples to RH variation over daily cycles and recording the mass change within the sample. The variables considered by the protocols are the time steps, the RH levels, the dimensions of the samples and the surface resistance (associated with the air velocity). The protocol was realised according to the proposed set up in the Nordtest [2]. A climatic chamber was used to set cycles of either 8 h at high RH and 16 h at low RH. Two different RH levels were used to investigate the behaviour of the material in different conditions.
cycles. A cycle of 8 h at 75% RH followed by 16 h at 33% RH and a cycle of 8 h at 85% RH and 16 h at 50% RH. The adsorption process and desorption phases were recorded after the samples remained in the chamber for at least 4 cycles, therefore ideally reaching dynamic equilibrium where the final mass at the end of the cycle and the initial mass vary by less than 5%. The mass of samples was recorded outside the chamber to avoid vibration from the ventilation in the chamber and to be able to measure a number of samples at the same time. The weighing was done in a rapid process under 3 min that does not affect the overall results from the test, as demonstrated in a previous publication [27]. The practical Moisture Buffering Value (MBV practical) is calculated using the maximum moisture uptake (g/m²) after the 8 h adsorption phase divided by the RH interval, which, in this case, is either 42% for cycles from 33% RH to 75% RH and 35% for cycles from 50% RH to 85% RH. Moisture buffering value (MBV) is expressed in g/(m².%.RH) and this single value varies depending on the RH levels and time step used. In the reminder of this article, this test will be referred to as the moisture buffering test.

The maximum standard deviation observed for the moisture buffering test realised on three identical samples is 0.15 g/(m².%.RH). The weighed variance on 41 sets of three identical samples is 0.07 g/(m².%.RH). This represents a good repeatability of the test.

### 4. Results and discussion

Changes in properties of soils influence static hygric properties such as water vapour transmission and moisture storage capacity, which impact moisture buffering. Each property and their relative influence on moisture buffering are presented in the next two sections.

#### 4.1. Water vapour transmission

**4.1.1. Properties affecting water vapour transmission**

The apparent density represents the mass per unit volume of the sample including the voids and can affect the porosity and permeability of soils. The dry mass was determined after placing the samples for 24 h in an oven at 105 °C. The volume of the samples was measured to a precision of 0.01 mm using a digital calliper. The influence of the apparent density on the water vapour resistance factor is given in Fig. 2.

The correlation between apparent density and water vapour resistance was investigated by calculating Pearson’s correlation coefficient. The correlation is weak for groups I, VII, VIII and IX and negative for groups II and III. The poor correlation can directly be related to the variability within the group. The addition of stabiliser in group I has an influence on the porosity and the water vapour resistance factor without affecting the apparent density due to crystallisation products. The weak correlation in group VII shows that the particle size distribution and mineralogy of the soil has a greater influence on the water vapour resistance factor than solely the apparent density. Groups, were the apparent density is the only variable, have strong correlation, see Table 3. It can be noted in Fig. 2 that the effect is different for groups IV, V and VI which have a very similar composition compared to groups II and III.

It can be concluded that there is a relation between apparent density and moisture transmission which is only valid if there is no alteration to the nature of the soil.

**4.1.2. Influence of apparent density and moisture transmission on MBV**

Plotting apparent density and MBV in Fig. 3 does not show any direct relation between them. The samples in group IV and V with similar mineralogy have a small variation in MBV compared with the apparent density range. On the other hand a great variation of MBV is observed for samples with similar density but varying mineralogy and particle size distribution. Previous research with these soils [27] has also shown that stabilisation with 4—8% cement or lime reduces the MBV by up to 20%. The difference between groups V and VII which have a similar density but different mineralogy and particle size distribution is up to 350%. This indicates that the soil selection (soil mineralogy and particle size distribution) is likely to have a far greater influence on the moisture buffering value than changes that can be imparted to a soil (stabilisation, mixing method or change in density).

The water vapour resistance plays a significant role in the moisture buffering performance of unfired clay masonry. Fig. 4 plots the results of the water vapour resistance factor and the experimentally measured MBV for all samples.

As shown, there is a clear correlation between the MBV and the water vapour resistance. Fig. 4 also shows that there is a large variability within the unfired clay materials. The vapour resistance factor varies between 4.3 and 12.9. These results can be compared with the average values of conventional building materials obtained during the Nordtest project [2], as shown in Fig. 5. There appears to be a lower value (about 5) where further reductions in vapour resistance are not responsible for improving MBV, which suggests that the MBV is then improved by other material properties such as the moisture capacity.

#### 4.2. Moisture capacity

**4.2.1. Properties affecting moisture capacity**

The moisture storage capacity is determined by sorption isotherms. The moisture capacity indicates the difference in equilibrium moisture content (EMC) between two chosen RH levels in the

![Fig. 3. Influence of apparent density on the moisture buffering value.](image-url)
hygroscopic domain. It does not reflect the total saturation of the sample with liquid water. The hygroscopic behaviour is described by the adsorption process of water molecules on the surface of the clay particles and in a second phase by the filling of micropores and mesopores (capillary condensation) [34]. An illustration is given in Fig. 6 corresponding to the typical shape of pores in clay materials, typical pores are slit shaped.

The multilayer adsorption illustrated in Fig. 6, depends on the affinity of the particles to water molecules and the available surface area. Clay minerals typically have a very high affinity to water molecules, however differences exist between clay minerals [35,36]. Kaolinite type clay minerals have a lower surface affinity and surface area than Montmorillonite type clay minerals [37] which have a higher surface area due to their active interlayer space, see Fig. 6. Samples in group VI were prepared with an increasing content of Bentonite (a clay mixture mainly composed of Montmorillonite type clay). The addition of this swelling clay has an effect on the storage capacity of the material as it can be seen through the sorption isotherms in Fig. 7. There is an increase in both the moisture capacity and the hysteresis effect with increased Bentonite content. The sorption isotherms for samples with an apparent density of 1615 kg/m$^3$ and 2039 kg/m$^3$ in Fig. 8, show that while the apparent density has a low impact on the moisture capacity, the adsorbed quantity is only slightly reduced in the region of higher RH by an increase in apparent density. The adsorption at higher RH is governed by capillary condensation [34] which indicates that a higher density influences the pore structure and
therefore capillary condensation, which then affects the equilibrium moisture content (EMC).

Hysteresis represents the difference between the adsorption and desorption curves in sorption isotherm. The moisture capacity is usually determined by the slope of the adsorption curve, given by the following equation:

\[ x = \frac{du}{d\varphi} \]

Where \( u \) is the EMC (kg/kg) and \( \varphi \) is the RH. This is further discussed in Section 4.4.1.

4.2.2. Influence of moisture capacity on MBV

The moisture capacity obtained from DVS measurements on the section between 30% RH and 80% RH can be compared with the results obtained for the MBV with the climate chamber. Fig. 9 shows the results of the moisture capacity obtained for all soil mixes that were measured with the DVS. Measurements with the DVS were realised on small samples (less than 1 g) with all surfaces of the samples exposed except that in contact with the balance, unlike the samples in the climate chamber where only one surface was exposed. A clear trend is visible, the comparison yields a linear correlation coefficient of 0.82, which indicates that the moisture capacity is to a certain extent influencing the MBV variation observed at lower water vapour resistance values for unfired clay masonry. The higher the moisture capacity (slope of the sorption isotherm) the higher seems to be dynamic adsorption of the experimentally measured samples.

4.3. MBV derived from steady-state hygric properties

The MBVideal has been calculated to compare with the experimental results. The equation (1) given by Rode, Peuhkuri [2] was used to determine moisture effusivity, \( b_m [kg/(m^2.Pa.s^{1/2})] \):

\[ b_m = \sqrt{\frac{d_p \cdot \rho_0 \cdot \frac{\delta_p}{\rho}}{p_{sat}}} \] (1)

Where \( d_p \) (kg/m.s.Pa) is the water vapour permeability, \( \rho_0 \) (kg/m^3) is the dry density of the material, \( p_{sat} \) (Pa) is water vapour saturation pressure, at 23 °C. Using the moisture effusivity, equation (2) from Rode, Peuhkuri [2] was then used to calculate the MBVideal:

\[ MBV_{ideal} = 0.00568 \cdot p_{sat} \cdot b_m \cdot \sqrt{t_p} \] (2)

Where \( t_p \) is the time period used during the test. The relation between calculated and experimental data is shown in Fig. 10.

The same comparison was realised in a previous publication [27] on samples from group I, in this case more data was available and confirms that a good estimation of dynamic behaviour can be obtained from steady-state hygric properties. Mathematically the MBVideal represented in Fig. 10 is the combination of individual properties represented in Figs. 3, 4 and 9 through equations (1) and (2).

4.4. Investigation on the dynamic sorption using a DVS test equipment

The DVS equipment was primarily used to measure sorption isotherms, but as the test procedure can be entirely programmed, several tests were attempted to further characterise the dynamic sorption behaviour. The system uses a microscale to precisely record every minute the mass change of a sample placed within a chamber were RH and temperature can precisely be controlled and
pre-programmed therefore more information could be retrieved then solely the sorption isotherms. The moisture buffering test could be reproduced (Section 4.4.1) which gave precious information on the role of the hysteresis during the moisture buffering test. From the measurement of sorption isotherms information on the adsorption rates in between RH levels could be further analysed (Section 4.4.2). The dynamic data obtained could be compared to the dynamic data from the moisture buffering test (Section 4.4.3).

4.4.1. DVS moisture buffering test

The moisture buffering test was simulated with the DVS using the same time and RH levels used for this research. In Fig. 11 it can be seen that in the DVS, the sample reaches EMC (the asymptotic curve is reaching the plateau) within the time normally allowed for adsorption and desorption during the moisture buffering test.

During this test the sample is first allowed to reach its dry state at 0% RH. This is to make sure the sample follows the adsorption path of the sorption isotherm. It then reaches equilibrium at 50% RH, the RH is then increased to 85% once the sample has reached the EMC it is again lowered to 50% RH. The EMC reached during the second phase at 50% RH is higher than the previous one because it corresponds to a point on the desorption curve of the sorption isotherm. This is expected to occur in transient levels in the moisture buffering test. Therefore a more accurate determination of the moisture capacity that is active during the moisture buffering test would be to calculate the slope between the EMC on the desorption curve (for the low RH) and the EMC on the adsorption curve (for high RH), see Fig. 12. A different slope would be used to determine the moisture capacity if taken into account the hysteresis, $du_1$ is the difference in EMC on the adsorption curve which is normally used whereas $du_2$ is the difference when taking into account the hysteresis.

4.4.2. Variation in adsorption rate

During the measurement of the sorption isotherm the RH is gradually increased, for each RH step the sample reaches EMC before the next RH step, see Fig. 13 which presents the typical mass change for adsorption and desorption dynamics for RH% steps.

The DVS records the mass of the sample every minute and can therefore give precise indication on the adsorption rates between each RH step. Fig. 14 shows the adsorption rates for variable % RH steps occurring at higher RH which also indicates that the moisture capacity is non-linear over the RH range.

4.4.3. Comparison between small and large scale moisture buffering test

In Fig. 15 a comparison is made between the moisture buffering tests realised with the DVS on a small sample with no sides of the sample being sealed, the moisture buffering test realised in the climate chamber on. The two tests were realised with the same material it is therefore expect that they have equal equilibrium moisture content at 85% RH. The adsorption rate to reach EMC is however very different, because the size is the only varying parameter it means the reduction of adsorption rate in the larger samples is primarily due to the delay in the vapour transmission through the material. This indicates that the buffering potential of
leaving the sample to equilibrate at 50% RH and then increasing to 12 h. The results are classified in 3 groups WS I, WS II and WS III (wasserdampf adsorptionsklasse) [38]. The last class (WS III) is for materials with a moisture adsorption of more than 60 g per m² after 12 h. The materials tested in this study have a much wider range and the maximum adsorption after 8 h ranges from 47 g/m² to 157 g/m² in the 33/75% RH cycle and from 54 g/m² to 170 g/m² in the 50/85% RH cycle. Most materials would therefore classify as WS III in the German classification. For both classifications, additional groups would be needed to better characterise the highly adsorbing materials used for this study.

4.5. Classifying unfired clay masonry MBV

Considering the previous discussions, the moisture buffering test is an image of the transient adsorption states under specific boundary conditions. By using the same boundary conditions, the test can be used as a tool to compare the adsorption dynamics of building materials. As seen in Figs. 4 and 5, the MBV for all the measured unfired clay masonry samples varied between 1.13 and 3.73 g/(m².%RH).

According to the classification given by the Nordtest project [2], all the materials test classify as good or excellent buffering materials. It would be useful to determine a classification specifically for clay, similar to what has been done in Germany for clay plasters. The German test determines the water vapour sorption after 12 h. The materials tested in this study have a much wider range and the maximum adsorption after 8 h ranges from 47 g/m² to 157 g/m² in the 33/75% RH cycle and from 54 g/m² to 170 g/m² in the 50/85% RH cycle. Most materials would therefore classify as WS III in the German classification. For both classifications, additional groups would be needed to better characterise the highly adsorbing materials used for this study.

MBV obtained from different RH cycles should not be compared directly. However the correlation between the MBV from a 33/75% RH cycle to a 50/85% RH has been found in previous work to have a linear trend [27]. Fig. 16 shows the results for all samples measured in two different cycles, these further confirm the trend previously observed. The slope from the trend line can be used as a good estimation for those materials from one cycle to another. It can be noted that cycles with a smaller interval, from 50% RH to 85% RH have higher MBVs than samples with a larger interval, between 33% RH to 75% RH, most likely because of the increase in isotherm gradient at higher humidity levels (see Fig. 12).

5. Conclusions

The moisture buffering value of unfired clay masonry covers a large range of performance and varies between 1.13 and 3.73 g/(m².%RH) according to the Nordtest project method.

The MBV is greatly influenced by the rate of water vapour diffusion through the material. It has been shown in the DVS experiment that the adsorption dynamic of the water molecules on the solid interface is very fast and in most cases the vapour diffusion will reduce the overall buffering potential. Therefore the MBV can be improved by increasing the rate at which the water vapour reaches into the deeper layers of the material. A water vapour resistance factor of 4—5 has however been observed as a lower limit for CEB and earth plasters below which it has little influence on the MBV.

The MBV can be further improved by increasing the moisture capacity of the material. It has been shown that the nature of the clay minerals will have a great influence on the moisture capacity. The moisture storage capacity is influenced by the variable surface charge of the clay particles and their size. Adding finer and more active clay minerals such as a Montmorillonite significantly increases the moisture capacity but may have secondary effects such as increased swelling and shrinkage with changes in moisture.
Through these results it is clear that there is a great potential to even further improve the capacity of commercially available clay plasters and unfired clay masonry products to regulate the indoor humidity. The selection of soils (particularly mineralogy and particle size distribution) has a greater effect on moisture buffering than any changes that can be imparted to an existing soil (stabilisation or changes in density).

The classification presented by Rode et al. [2] and the German industry classification could be extended for clay materials as most of them can be classified as excellent and it is therefore difficult to distinguished between them.

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