# Adding waste paper to clay plaster to raise its ability to buffer moisture

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**Abstract.** The Nordtest method evaluates the moisture buffer value (MBV) of materials that are being exposed to indoor air. The test simulates daily variations (high RH of 75% for 8 hours, low RH of 33% for 16 hours) in MBV, which in this context refers to the moisture uptake/release in the material when it is exposed to relative humidity (RH) in a square wave. We are looking for ways to increase clay plaster's ability to buffer moisture. Which material has simultaneously a higher ability to buffer moisture and can be added to the clay plaster mixture? The recipe for the specimen included the following: waste paper (newspaper paper), glue (methylcellulose), clay and water. Our research showed that adding paper plaster mixture to the clay plaster mixture increases the moisture buffering ability of the plaster. The bigger the amount of added paper plaster, the better the plaster's ability to buffer moisture.

**Key words:** materials science, composite material, moisture buffer value, nordtest, plaster, clay, wastepaper.

## 1. INTRODUCTION

Today, the increasing demand for non-renewable resources may be balanced by a more efficient use of materials, by discovery of new sources, and by development of smart solutions. Renewable materials have high potential to become alternative energy sources to currently used intensive building materials such as cement, materials based on gypsum etc. This research can have far-reaching impact on the future of the building sector, especially green housing and renovation of historical buildings as it provides valuable data for national and international standards. The use of natural, traditional, recyclable/reusable surface finish materials provide a healthy, aesthetically appealing and comfortable indoor climate. Indoor climate parameters have a significant impact on human health and productivity, especially in our region (the Baltic states and the Nordic countries) as most of the population spends significant amount of time indoors.

Plastering as a building technique has long traditions in construction. Today it plays an important part in crafts of cultural heritage, both in Baltic and Nordic countries. Guidelines for products and design keep developing and when promoted they have a direct impact on future generations. In terms of old buildings' historic significance, the quality of retrofitting them will improve, as knowledge about the performance of existing plasters widens and unnecessary alterations to prove the fire safety of these old structures are excluded. Therefore, this project contributes to this tradition and provides design solutions for the authentic restoration and renovation of existing buildings.

The moisture buffering capacity of building materials is increasingly recognized for its beneficial influence on the indoor environment which has associated benefits for the whole building energy performance [5–7,9,10], for moisture buffer effect and its impact on indoor environment [11]. In historical buildings, 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. Hygroscopic

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materials such as unfired clay have high potential to provide these functions in a building [6]. Most of the research focusing on moisture buffering investigates its overall influence on the hygrothermal performance of a building and how this can be simulated [1,7]. In some cases, clay material was studied in combination with other materials such as organic waste [4] or fibrous materials, for example hemp [13] and waste paper [14] .

Value of materials (MBV) was studied by several authors [3,8–10]. During the study of clay plaster, it was established that clay has good capacity of moisture buffering [2,12]. Other hydrothermal properties of clay plaster have also been studied, for example the sorption and water vapour permeability [9]. The current study was directed to the improvement of clay plaster's ability to buffer moisture.

## 2. METHOD

The method used in this study is described in detail by Rode [9]. A partly sealed sample is exposed to repetitive changes in ambient relative humidity, where the temperature is held constant at 23 °C. The change in RH will result in the specimen gaining or losing weight and this change is determined by either continuous monitoring or frequent weighing. The change in weight over certain time can be considered as an expression of the MBV of the test specimen.

The equipment used in study: climate chamber RUMED 4101, affording RH between 20 and 95% with accuracy ± 2–3% and temperature between 0 and 60 °C with accuracy ± 0.5 °C; Memmert Incubator Oven INB200, in the temperature range from + 30 °C (however, at least 5 °C above ambient) up to + 70 °C; and digital balance Kern PLT 1200-3A with accuracy of 0.001 g. Climate chamber was used for the environment's temperature of 23 ± 0.5 °C with five specimens of each type.

A climate chamber is included in the experiment. In this chamber the temperature and RH can be kept on a constant level and necessary RH can be performed. In addition, suitable sensors and a logging system are used to continuously record the temperature and relative humidity inside the test chamber. An analytical balance, capable of weighing the test specimens with the repeatability of 1% is also used. The air in the test chamber should circulate and the air velocity, as in a normal indoor environment, should be 0.10 ± 0.05 m/s.

Test specimens' shape and size are not fixed (recommended minimum side length or diameter of the exposed area of the specimen is to be 100 mm, and minimum exposed face area 0.01 m²).

The area should be set within an accuracy of 1%. If the total surface area is homogeneous and at least 0.03 m², then representative smaller test specimens are allowed.

Test specimens should be sealed on n-1 out of n. Materials used for sealing should not absorb moisture.

Thickness of samples must be the same as their intended use or as the depth of moisture penetration (1% definition) for daily variations in moisture. At least three test specimens should be tested.

At first (before testing), the specimens were stored and kept in equilibrium with air at 23 ± 5 °C and RH at 50 ± 5%. The criterion for the equilibrium is defined as a period that is long enough for the weight of the specimen to stabilize to a state where two successive daily determinations (24 hours in between) of the weight stay within 0.1% of the sample's mass.

Test conditions: temperature 23 °C, low RH 33%, high RH 75%. The high level of RH should last for 8 hours (± 10 min) and the low RH level for 16 hours (± 10 min). If the RH changes cannot be achieved instantaneously, then they should be measured to an accuracy of ± 3% RH within maximum of 30 minutes after the intended change. The planned temperature should stay within ± 0.5 °C.

The cyclic exposure should be carried out until the mass changes. During the last three cycles (days) the change in mass, $\Delta m$ [g], should be less than 5%. $\Delta m$ should be determined in each cycle as the average between the weight gain during the moisture uptake branch of the cycle and the weight loss during drying. In addition, the difference between weight gain and weight loss within each cycle should be less than 5% of $\Delta m$.

The weight gains and losses need to be continuously monitored and minimum of one weighting has to be done by the turn of each exposure in the cycle. During the 8-hour absorption period of the final three days the sample should be weighed 5 times at the minimum.

Preparation of the specimen and the test facility: test samples should be prepared; their thickness and the exposed area should be measured before and after sealing. Procedure should be tested and then weighing should be performed. The weight should be measured in an environment that has been set to a temperature within ± 2 °C of the test condition, anywhere within the test chamber. The result is not influenced by the movement to scale by more than 1% of the amplitude. A curve of the mass in time should be plotted.

### 2.1. Plaster mixtures and specimens

The specimens were made according to the recipe that contains: waste paper (newspaper paper), glue (methyl-cellulose), clay and water. The total number of specimens was 45 (5 × 9). Two different clays (< 0.2 and < 0.4 mm) were used and three different paper + clay proportions (g) (5:1, 1:1, 2:1) were used. Three control groups were used as follows (see Fig. 1 and Table 1):
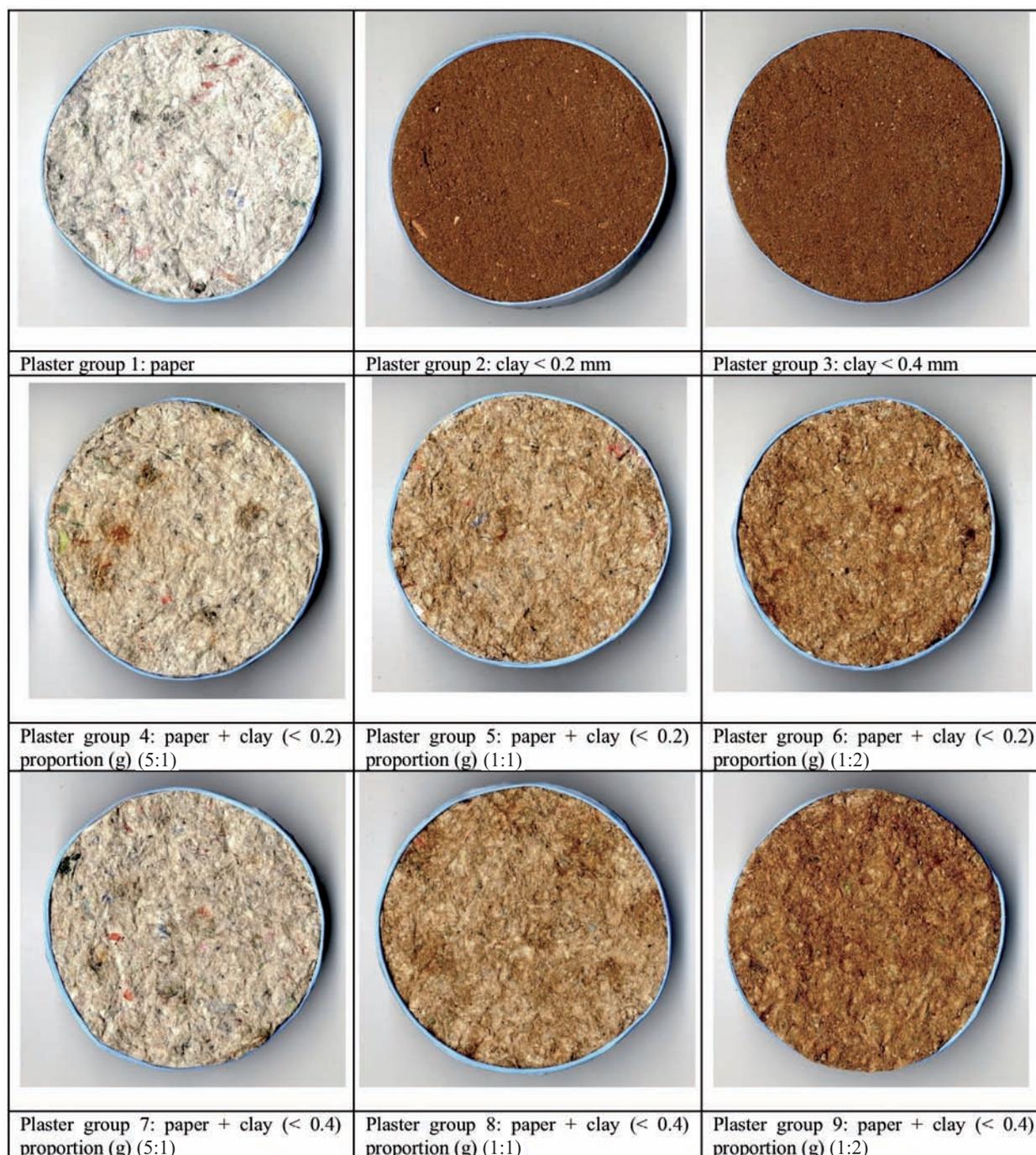
**Fig. 1.** Examples of specimen groups.

- paper;
- clay with grain size < 0.2;
- clay with grain size < 0.4 mm.

Two products of Saviukumaja OÜ were used as clay plaster mixtures:

(1) clay plaster base (clay, sand with grain size 0–4mm, with added grain straws/hemp shives and fibres);

(2) clay finishing plaster (clay, sand with grain size 0–2mm, with added fibre of the *Typha spadix*).

Mineralogical composition (weight ratios) of the clay plaster mixture (< 0.2 mm) was determined using X-ray diffraction analysis: quartz 45.6%, k-feldspar 6.6%, plagioclase 7.9%, chlorite 1.5%, illite/illite-smectite 20.9%, kaolinite 4.1%, calcite 8.5%, dolomite

**Table 1.** Composition of mixtures

| Plaster group | Plaster composition | Grain size of clay plaster (mm) | Paper (g) | Glue (g)/ water (g) | Clay (g) | Proportion (paper (g)/clay (g)) | Dry density (g/cm³) | Number of samples |
|---|---|---|---|---|---|---|---|---|
| 1 control | Paper | – | 500 | 20/1000 | 0 | 1/0 | 0.19 | 5 |
| 2 control | Clay | < 0.2 mm | 0 | 0 | 100% | 0/1 | 2.27 | 5 |
| 3 control | Clay | < 0.4 mm | 0 | 0 | 100% | 0/1 | 2.39 | 5 |
| 4 | Clay + paper | < 0.2 mm | 500 | 20/1000 | 100 | 5/1 | 0.25 | 5 |
| 5 | Clay + paper | < 0.2 mm | 500 | 20/1000 | 500 | 1/1 | 0.34 | 5 |
| 6 | Clay + paper | < 0.2 mm | 500 | 20/1000 | 1000 | 1/2 | 0.49 | 5 |
| 7 | Clay + paper | < 0.4 mm | 500 | 20/1000 | 100 | 5/1 | 0.22 | 5 |
| 8 | Clay + paper | < 0.4 mm | 500 | 20/1000 | 500 | 1/1 | 0.38 | 5 |
| 9 | Clay + paper | < 0.4 mm | 500 | 20/1000 | 1000 | 1/2 | 0.43 | 5 |

4.0%, hematite 0.5% and amphibole 0.5%, respectively [2].

The density of dry plaster made of clay plaster mixture with the grain size of < 0.2 mm is 2.27 g/cm³ and 2.39 g/cm³ with the grain size of < 0.4 mm, respectively. Density of dry plaster made of paper is 0.19 g/cm³ and the density of the dry clay plaster mixture used in the test stayed between 0.22 and 0.49 g/cm³ (see Table 1).

Thickness of the samples is approx. 25 mm (the same as their intended use) and diameter is approx. 90 mm.

## 3. RESULTS

In order to compare the moisture absorption of plaster mixtures and desorption studied in the test, an index for moisture buffering value (MBV) was used. $MBV_{practical}$ describes the changes in the moisture of materials in real situations in spaces related to people [3].

In the Nordtest experiment carried out to determine the MBV, the relative humidity was cyclically changed (8h RH = 75% and 16h RH = 33%) (see Fig. 2). As a result of cyclical changes in the relative humidity of the climate chamber the specimens' weight also changed in cycles (see Fig. 3).

The results were calculated as changes in mass: $\Delta m$ per m² and per $\Delta RH$. For each cycle two results of mass change were calculated: one for the weight gain during absorption ($m_{8\ hours} - m_0$) and one for the weight loss during drying ($m_{24\ hours} - m_{8\ hours}$). In each cycle the average between the absorption and desorption weight changes was calculated. On the basis of at least 3 cycles' average (see Fig. 2) the figure MBV was calculated.

Nordtest formula for $MBV_{practical}$ [g/(m²·%RH)] calculations (Eq. (1)):

$$MVB_{8h} = \frac{m_{max} - m_{min}}{A \cdot (\varphi_{high} - \varphi_{low})} , \qquad (1)$$

where $m_{min/max}$ is moisture mass (min and max) in final sample (g or kg); A is exposed area m²; and $\varphi_{high/low}$ is high/low RH levels applied in the measurement.

When using the moisture buffer values [g/(m²·% RH)@8/16h], materials can be classified as follows:
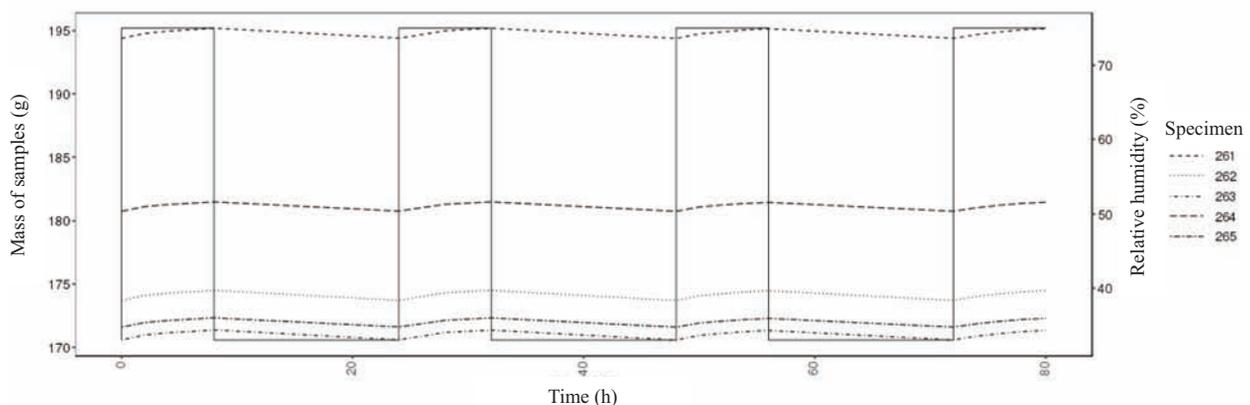


**Fig. 2.** The whole mass (g) of five samples (plaster group 5) in the cycles of Nordtest. The change in moisture cycles (RH 33% and RH 75%) in the climate chamber is portrayed by a continuous line.
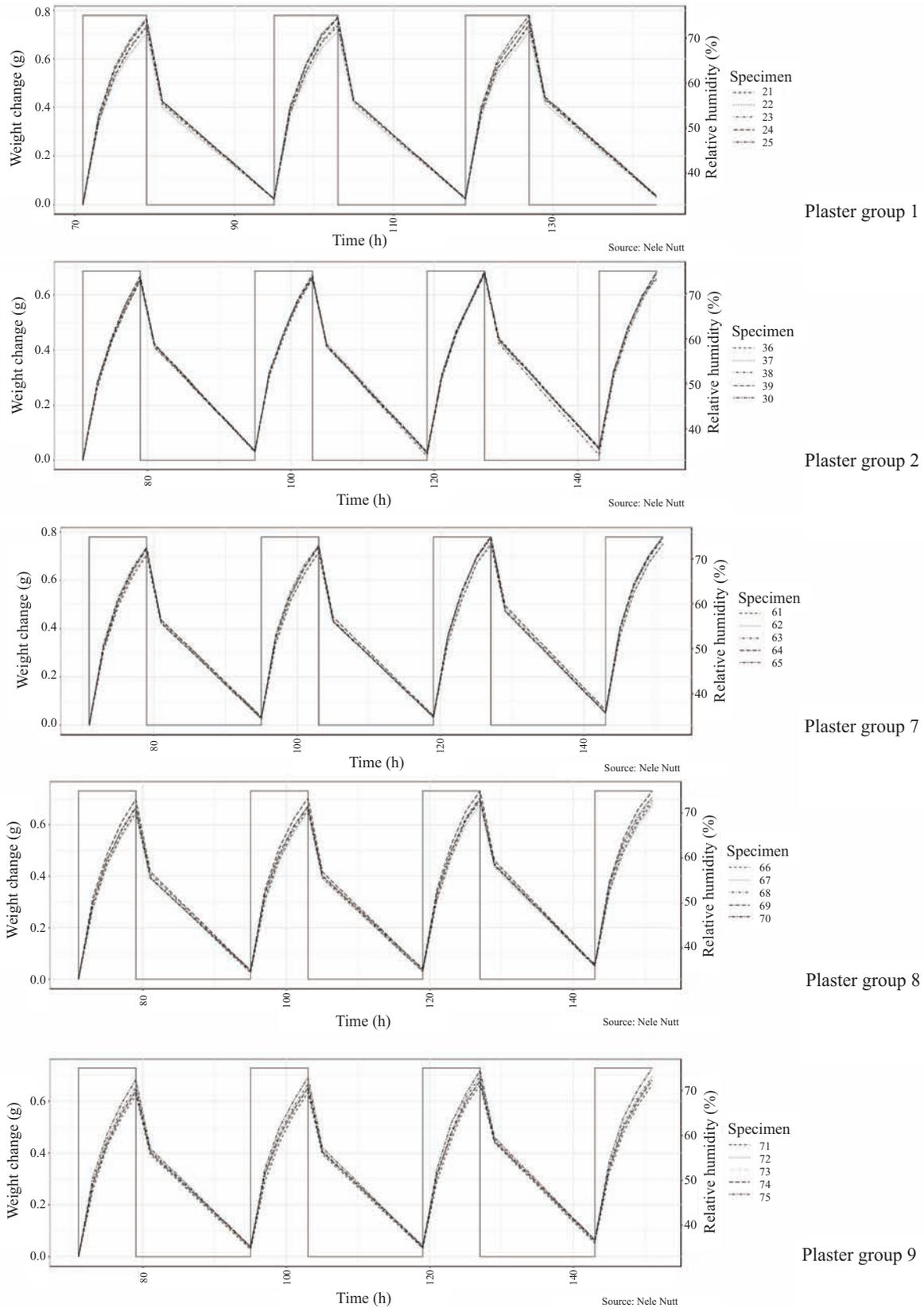
**Fig. 3.** Changes in specimens' weight (only weight change) in the final cycles (plaster groups 1, 2, 7, 8 and 9) of Nordtest. The change in moisture cycles (RH 33% and RH 75%) in the climate chamber is portrayed by a continuous line.

negligible (0–0.2), limited (0.2–0.5), moderate (0.5–1.0), good (1.0–2.0), and excellent (2.0–) [9].

Figure 2 shows the whole mass (g) of five samples (plaster group 5) in the cycles of Nordtest. The change in moisture cycles (RH 33% and RH 75%) in the climate chamber is portrayed by a continuous line.

Figure 3 shows the changes in specimens' weight (only weight change) in the final cycles (plaster group 1, 2, 7, 8 and 9) of Nordtest. The change in moisture cycles (RH 33% and RH 75%) in the climate chamber is portrayed by a continuous line.

The MBVs of plaster mixtures made of clay plaster mixture and paper plaster mixture used in the experiment stayed in the range between 2.34 and 2.73 g/(m$^2$·%RH)@8/16h (see Fig. 4). By using the MBV classification [9] all the mixtures with MBV value higher than 2.0 belong to a higher class (excellent) (see Table 2). Only the mixture that contained the paper plaster mixture had the highest MBV (2.77).

In the case of the clay plaster mixtures used in the experiment (plaster group 2 and 3), the MBV stayed below 2, but for all the plaster mixtures containing paper plaster, the value was significantly higher than 2. The most significant was the one that had the highest quantity (5:1) of paper plaster mixture (plaster groups 4 and 7) and the least significant was the mixture which had the least amount (1:2) of paper plaster added to it (plaster groups 6 and 9) (see Fig. 4).

## 4. DISCUSSION AND CONCLUSIONS

Our experiment showed that adding paper to the clay plaster mixtures changes the hydrothermal properties of

**Table 2.** Density and MBV of mixtures.

| Plaster group | Dry density (g/cm$^3$) | MBV [g/(m$^2$·%RH) @8/16h] | MBV classification |
|---|---|---|---|
| 1 | 0.19 | 2.77 | Excellent* |
| 2 | 2.27 | 1.56 | Good* |
| 3 | 2.39 | 1.89 | Good* |
| 4 | 0.25 | 2.73 | Excellent* |
| 5 | 0.34 | 2.54 | Excellent* |
| 6 | 0.49 | 2.46 | Excellent* |
| 7 | 0.22 | 2.63 | Excellent* |
| 8 | 0.38 | 2.37 | Excellent* |
| 9 | 0.43 | 2.34 | Excellent* |

* Negligible (0–0.2), limited (0.2–0.5), moderate (0.5–1.0), good (1.0–2.0), excellent (2.0–).
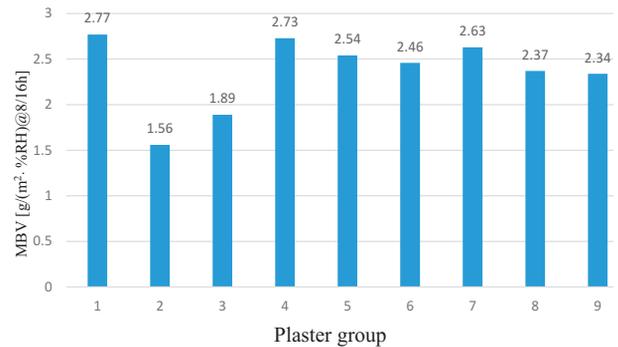


**Fig. 4.** MBV of plaster groups.

the clay plaster mixture. The research determined that adding paper plaster to clay plaster increased the moisture buffering ability of the plaster.

- The moisture buffering value (MBV) increases after adding paper plaster mixture to clay plaster mixture. MBV of paper plaster was 2.77 g/(m$^2$·%RH)@8/16h, MBV of clay plaster stayed in the range between 1.56 and 1.89 g/(m$^2$·%RH)@8/16h and the MBV of combined mixture was in the range between 2.34 and 2.73 g/(m$^2$·%RH)@8/16h.
- MBV depends on the amount of paper used. The larger the proportion of paper in the mixture, the higher the moisture buffering value of plaster mixture. The mixture with the smallest proportion of paper (paper/clay 1:2) had MBV of 2.34 g/(m$^2$·%RH)@8/16h and the largest proportion of paper (paper/clay 5:1) in the mixture had a MBV of 2.73 g/(m$^2$·%RH)@8/16h.
- Adding even a small amount of paper in the mixture has an impact on the increase of the MBV. When the MBV of clay plaster is between 1.56 and 1.89 g/(m$^2$·%RH)@8/16h, the MBV with paper/clay ratio 1:2 remained between 2.34 and 2.46 g/(m$^2$·%RH)@8/16h.
- Adding paper plaster to clay plaster decreases the density of clay plaster (density of paper plaster 0.19 g/cm$^3$, density of clay plaster 2.27–2.39 g/cm$^3$). The densities of mixtures (paper/clay 5:1) range from 0.22 to 0.25 g/m$^3$ and (paper/clay 1:2) from 0.43 to 0.49 g/m$^3$.

It would be promising to study also the countereffect – how clay plaster properties improve the properties of paper plaster as opposed to how paper plaster properties improve clay plaster. As the first hypothesis, we can suggest that the mixture of clay plaster as a mineral material has fire-resistant qualities and presumably the fire-resistance of paper plaster can be increased by adding clay plaster. Secondly, the amount of water added to clay plaster is much smaller (approximately two times) than the amount added to paper plaster. Plaster mixtures dry

and solidify through the evaporation of water, which is why a wall covered with paper plaster takes significantly longer time to dry (approximately two weeks) compared to a wall covered with clay plaster.

Another positive aspect appeared after adding paper to clay plaster. The plaster made of paper and clay mixture behaves similarly to paper plaster when in use (plastering a wall) which means that the paper combines the plaster into a wholesome mass that does not fall off like clay plaster and it can be used in the same manner as paper plaster. Paper plaster does not require special tools or technique unlike clay plaster, hence, using paper plaster is feasible to everyone and does not expect special skills.

Studying the properties of plaster mixtures made of paper and clay plasters is very promising because the final mixture acquired the properties of paper plaster through the added paper. In addition, the appearance of positive qualities when adding clay plaster mixture to the paper plaster (fire-resistance, speed of drying) should be studied.

**ACKNOWLEDGEMENTS**

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## Savikrohvi niiskuspuhverdusvõime tõstmine paberjäätmete lisamisega

Nele Nutt, Ardo Kubjas ja Lembit Nei

Nordtesti meetodi eesmärk on simuleerida eluruumis toimuvaid ööpäevaseid suhtelise õhuniiskuse tsüklilisi muutusi (suhteline niiskus 75% 8 tunni ja 33% 16 tunni jooksul), et määrata siseõhuga kokkupuutuvate materjalide niiskuspuhverdusvõime. Otsime võimalusi savikrohvi niiskuspuhverdusvõime tõstmiseks. Millisel materjalil on samaaegselt suurem niiskuspuhverdusvõime ja mida saab savikrohvisegusse lisada? Katses testitud segu retsept koosnes vanapaberist (ajalehepaber), liimist (metüültselluloos, Henkeli toode), savikrohvist (Saviukumaja OÜ toode) ja veest. Meie uuringud näitasid, et paberkrohvisegu lisamine savikrohvisegule suurendab krohvi niiskuspuhverdusvõimet. Mida suurem on lisatud paberi kogus, seda kõrgem on komposiitkrohvi niiskuspuhverdusvõime.