Jan Růžička, Jakub Divis, Kamil Stanek, Jan Richter
CVUT Faculty of Civil Engineering, Prague, CZ

The influence of natural clays and earthen structures on the relative humidity of internal microclimates

Relative indoor humidity is one of the crucial indicators regarding quality of internal microclimate. Low humidity level can cause dry skin, throats and nasal passages and can cause annoying static electric sparks. High humidity level can lead to growth of moulds and bacteria and can cause condensation problems on cold surfaces. ASHRAE standard 55 (ANSI/ASHRAE 2004) recommends comfort zone from temperature 68 and 80 °F and relative humidity of 20 – 80%, whereas the higher temperature the lower relative humidity and vice versa. European authors as Jokl (1991) recommend optimal indoor humidity in the range of 30 – 70% by temperature 19 – 24°C. Korjenic et al (2010) states optimal levels of indoor humidity for human beings in Austrian climate in the range of 40 – 60% of which upper limit is preferred in winter and lower limit in summer.

Materials that absorb and release moisture can be used to reduce and accumulate extreme values of moisture and can supply moisture in case of dry periods. The main advantage of using building structures to moderate indoor environment is to use the mass and to reduce operating energy.

Clay minerals compared to other building materials can be effectively used according to their mineralogical composition as a storage for indoor humidity to keep the required level. At the same time clay materials and earthen structures are considered as environmental friendly due to lower values of embodied CO_2 and SO_2 emissions and embodied energy, can be fully and easy recycled at the end of the life span of the building and have unlimited lifetime.

Although natural clay has excellent sorption properties, in practical use clay materials contain certain amount of sand primarily to minimize shrinkage. Typical clay plasters contain 70 – 75% of sand which decrease rapidly sorption ability. Such a high amount of sand means that the sorption properties of clay plaster are at the same level as traditional lime-cement plasters. Also other factors as chemical stabilization, the way of drying, mineralogical composition etc. have to be taken into account from the point of view of sorption potential of clay and earthen structures.

Testing methods of sorption properties of building materials

Sorption

To compare sorption of single building materials sorption test according to the European Standard EN ISO 12571:20134 is recommended. The experimental measurement of sorption properties is carried out in the glass desiccator at a constant temperature and atmospheric pressure. Aimed relative humidity in the desiccator is achieved by saturated salt solutions. The test samples are exposed to the relevant environment until reaching the equilibrium weight. This state is achieved when the weight change during 24 hours is less than 0.1%. Sorption curve of the tested material which describes the potential to accumulate air humidity is the result of the experiment and can be compared to other single material. The formula of sorption curve can be used for further mathematical simulations. The main disadvantage of this kind of test is that is doesn't say anything about the real building structure which typically consists of several materials in several layers.

Moisture buffer value test and other experimental methods

There are several experimental methods trying to describe the influence of building materials on indoor relative humidity. Some of them have been proposed by Time (1998), Padfield (1999), Hansen et al (2000) etc. Simonson et al (2002) gives an example how wood based structures can significantly reduce the

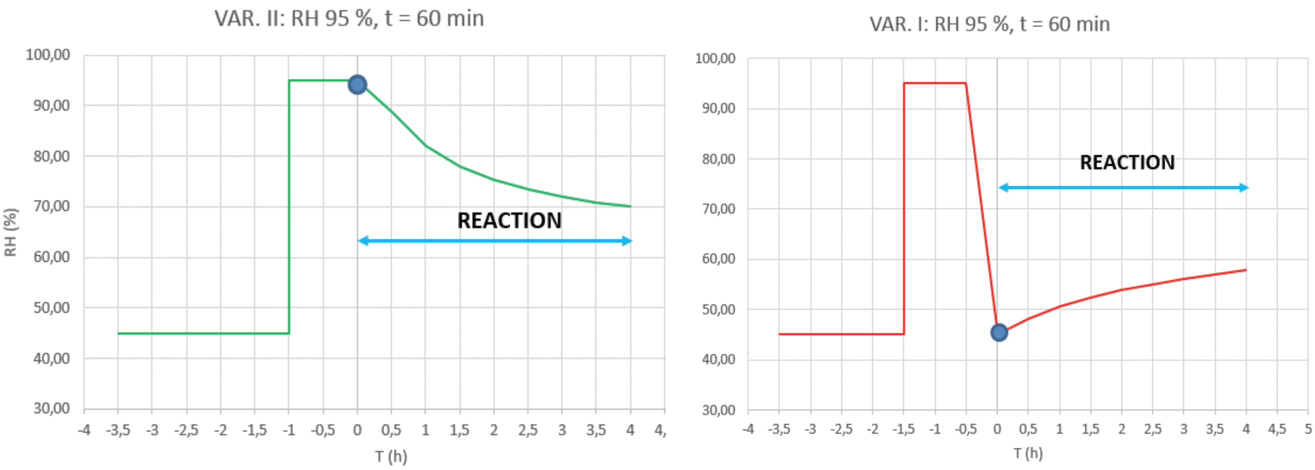


Fig. 1 Test set up of dynamic behaviour of building structures under the influence of moisture changes – adsorption test (left), desorption test (right).

peak of indoor humidity (by as much as 35%) and increase indoor humidity (up to 15%). Full scale measurement of moisture buffering in building materials have been carried out by Mitamura et al (2001).

Rode (2005) within the NORDTEST project proposes a test protocol for experimental determination of the moisture buffer value. The test protocol proposes climatic exposure which vary in 8 h + 16 h cycles: 8 h of high humidity and 16 h of low humidity. The reason comes from usual daily cycle which is 8 h as sleeping time, working hours etc. and also from practical reasons during the test. The low humidity is proposed 33% RH and the high level 75% RH, however other humidity levels are proposed according to saturated salt solutions as 33/54%, 54/75% and 75/93%. Also the size of test specimens is recommended so the minimum of exposed surface area is 0.01 m^2 and the thickness should be at least the moisture penetration depth for daily humidity variations or 10 mm. A minimum 3 cycle test have to be carried out. This test also describes sorption properties of single materials.

Full scale moisture buffer value test

An interesting full scale test of moisture buffer capacity of walls of the surface area of approx. 15.38 till 20.24 m^2 was carried out by Mortensen et al (2005). Plasterboard construction and cellular concrete wall were tested. The idea was to mimic the exposure of moisture variations to interior surface materials. To measure moisture buffering effect of the structures the room was subjected to controlled moisture variations. The results proved that moisture buffer capacity of materials can be used to reduce humidity variations of the indoor environment.

Full scale test of dynamic sorption for building structures

To gather reliable and valid results of behaviour of the complete structures the appropriate testing method has to be developed. The main idea of dynamic sorption test is to simulate real situations in the building and behaviour of real building structures in "real" conditions. The proposed test protocol is based on following situations:

1. internal environment is in equilibrium state, for example 45% RH: (in real situation the room is empty, no one is there),
2. internal environment is facing intensive increase of relative humidity, for example up to 95% RH for specific period 60 minutes (in real situation someone is taking shower or bath, cooking, doing or drying the washing etc.).

After step 2, the following scenarios are possible:

3a. at the end of the high humidity period of 95% it is observed how relative humidity in the room decreases which determines the potential of tested building structure to moderate the moisture

Table 1 Saturated solutions

Saturated solution	LiCl	$KC_2H_3O_2$	K_2CO_3	NH_4NO_3	NaCl	KCl	KNO_3	K_2SO_4
RH [%]	11.3	24.0	43.2	62.0	75.5	85.5	95.0	97.6

Sample	Material source / producer	Mineralogical composition	Comments	Volume density kg/m^3
Clay products				
Clay plaster	Picas		undercoat and finishing	1853
Unburned hollow brick	Heluz			1626
Clay board	Lemix			1356
C_S10/W10 (Richter et al, 2014)	Claygar mixture used for rammed earth panels based on Hydromicas and Kaolinite with minor addition of Montmorillonite with 10% sand and 10% mixing water			2033
Adobe	from a historical building from the end of 19th century in Western Bohemia (typical)			1664
Reference materials				
Ceramic hollow brick	Heluz			1259
Concrete				2131

Table 2 Overview of test samples

peaks and to absorb the moisture from the environment – adsorption potential of the building structure (Fig. 1 left),

3b. the room is ventilated for specific time period (for example 20 minutes) to the reach the starting level of internal humidity (45%) and it is observed how much moisture is absorbed in the structure it means how the internal humidity increases – desorption potential of the building structure (Fig. 1 right).

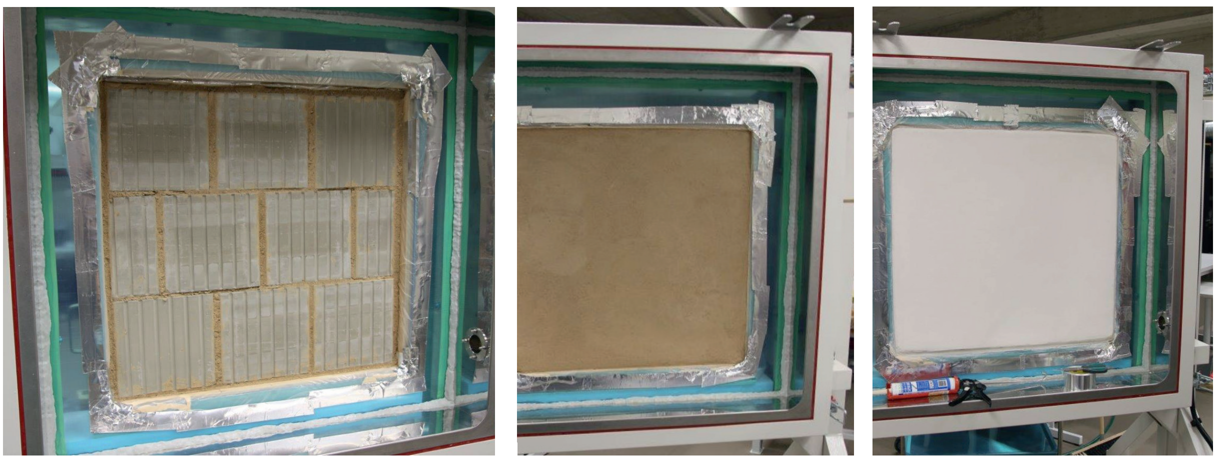
Results

Sorption

Sorption curve was carried out on test specimens of the size approx. 40 × 40 × 15 – 25 mm and of the weight about 50 – 60 g. All materials were measured in sets of 3 samples which were air-dried under controlled conditions (temperature 18 – 22°C, 40% RH) at the equilibrium weight as higher drying temperature in the drying room might change the structure of the material and its sorption properties. Aimed RH levels in the desiccator were created by saturated solutions (Table 1) and present the particular points in the sorption curve. The RH values mentioned in the Table 1 are only proximate. Exact RH values were measured by a datalogger. The weight was measured using a digital lab scale with precision of ± 0.005 g.

Determination of dry bulk density was carried out according to the European Standard EN 772-13 (2001). At the end of the experiment all materials were dried out in a drying room at 105°C to the constant weight to get correct numbers of dry bulk density. The linear

Fig. 3 Testing walls in the climatic chamber: Fair-face brickwork from unburnt clay bricks (left), unburnt clay hollow blocks with clay plaster (middle), ceramic hollow blocks with lime plaster (right)



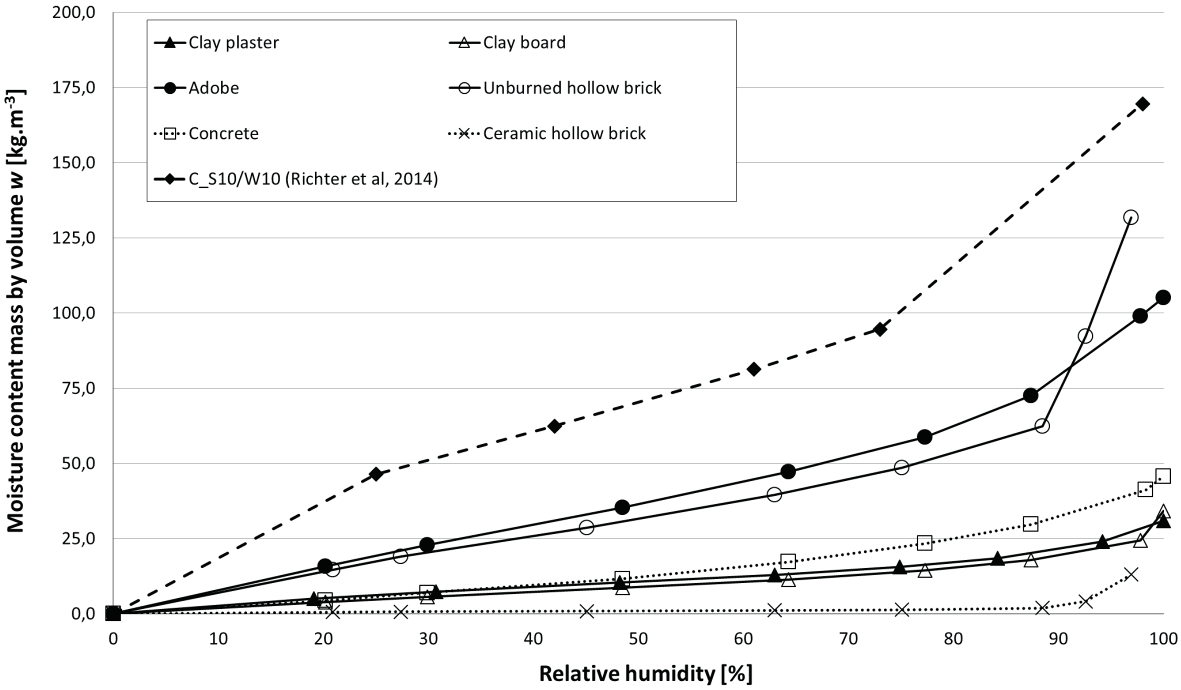


Fig. 2 Adsorption curves: comparison of different clay products and common materials.

dimensions of the samples were measured according to the EN 120856 by the electronic digital calliper with a precision of ± 0.005 mm. A samples' volumes were calculated from these dimensions.

Set of test samples (Table 2) covered materials and products available on the Czech market and materials used in walls tested for dynamic sorption: unburned hollow blocs Heluz, clay plasters PICAS, ceramic hollow blocs Heluz. To prove the differences among clay products also historical adobe brick, clay board Lemix and Claygar mixture used for prefabricated rammed earth panels were added and compared to common building materials such as concrete of the strength class C30/37 and ceramic hollow brick Heluz.

Differences in sorption potential among the materials are obvious from sorption curves in the Figure 2. Sorption isotherms of adobe and unburned hollow brick have almost similar shape and they reach half potential of the C_S10/W10 mixture for rammed earth panels. Sorption isotherms of clay plasters and clay board have again very similar curves but the sorption is very low compared to previous mixtures.

On the other hand comparison with commonly used materials was quite surprising and showed that the potential of sorption properties of some clay materials is sometimes overrated. Low potential of tested clay plasters and clay board due to the high amount of sand for decreasing shrinkage is obvious. The sorption potential is at the same level as concrete mixtures have! Poor ability to absorb moisture by ceramic blocks is also obvious.

Full scale test of dynamic adsorption/desorption

Dynamic sorption properties of real structural parts have been tested on the specimens of the size 820 × 750 mm in the climatic chamber WEISS WK3-1000/0-S with the volume 1.3 m^3. The test specimens were installed in wooden frame due to technological purposes. Rear side and perimeter of the test sample was covered by OSB of the thickness 12 mm and PE foil Gutta to avoid side moisture transfer. Following test samples were tested:

- Fair-face brickwork from unburned clay hollow blocks Heluz Nature Energy 12/25 of the thickness 120 mm,
- Unburned clay hollow blocs Heluz Nature Energy 12/25 of the thickness 120 mm with clay plaster PICASS ECONOM 22 mm,
- Ceramic hollow blocks Heluz 8 of the thickness 80 mm covered by lime plaster HASIT 160 Fein Kalkputz.

After the assembling the test samples were conditioned in laboratory conditions at 50 ± 10% RH and laboratory temperature of 23 ± 2°C for 2,5 month. Relative humidity in the climatic chamber either adjusted by the device or as a response of previous steps was measured continuously during the test.

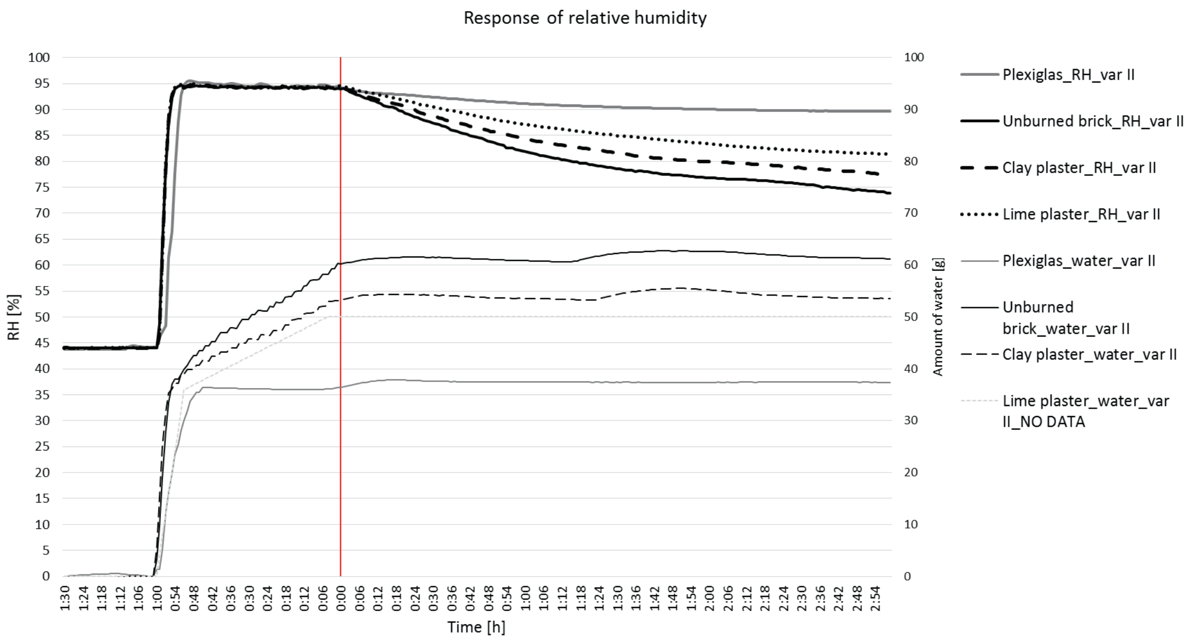


Fig. 4 Behaviour of test walls during dynamic sorption test

Also the amount of water used by the device to keep the adjusted RH level in the chamber was measures and is obvious on the right axes in Figure 4 and 5.

Dynamic adsorption test

This situation describes the behaviour of the test sample after the high humidity period finishes and moisture from the environment is accumulated to the tested wall. The test was carried out at the constant temperature of 23 ± 0.5°C in the climatic chamber and testing of dynamic sorption consisted of following steps (see also Fig. 1):

1. conditioning of the test sample at 45 ± 1% RH for 48 hours,
2. high level of humidity at 95 ± 1% RH for 60 minutes,
3. monitoring of RH changes in the climatic chamber for 16 hours.

As a reference test sample from plexi glass was used to prove the air and humidity tightness of the climatic chamber. Slight decrease of relative humidity in the chamber of about 10% is visible and has to be taken into account by final assessment. Differences in behaviour of test samples regarding the ability to absorb humidity and to decrease the peak are obvious. As expected uncovered unburned blocks have the highest potential and the ceramic blocs with lime plaster the lowest. The amount of water used to keep the level of 95% RH correspondents with the ability to sorb humidity.

Dynamic desorption test

This part of the test describes the behaviour of the test sample after the high humidity period finishes and relative humidity in the environment drops down to starting moisture level for example due to ventilation, open windows etc. The ability of tested structure to accumulate moisture in a short time period and to increase relative humidity gradually in the environment is observed. The test was carried out at the constant temperature of 23 ± 0.5°C in the climatic chamber and testing of dynamic desorption consisted of following steps (see also Fig. 1):

1. conditioning of the test sample at 45 ± 1% RH for 48 hours,
2. high level of humidity at 95 ± 1% RH for 60 minutes,
3. ventilation of the environment to the starting humidity level 45 ± 3% RH for 20 minutes,
4. monitoring of RH changes in the climatic chamber for 16 hours.

Plexi glass barrier has been used again to prove the air and humidity tightness of the device. As expected uncovered unburned blocs show the highest potential to increase relative humidity after the relative humidity drop-off and the potential to accumulate and to release moisture is similar to the behaviour of unburned blocks covered by clay plaster. The amount of water in the device used to keep the level of 95% RH is on the right axes of the graph.

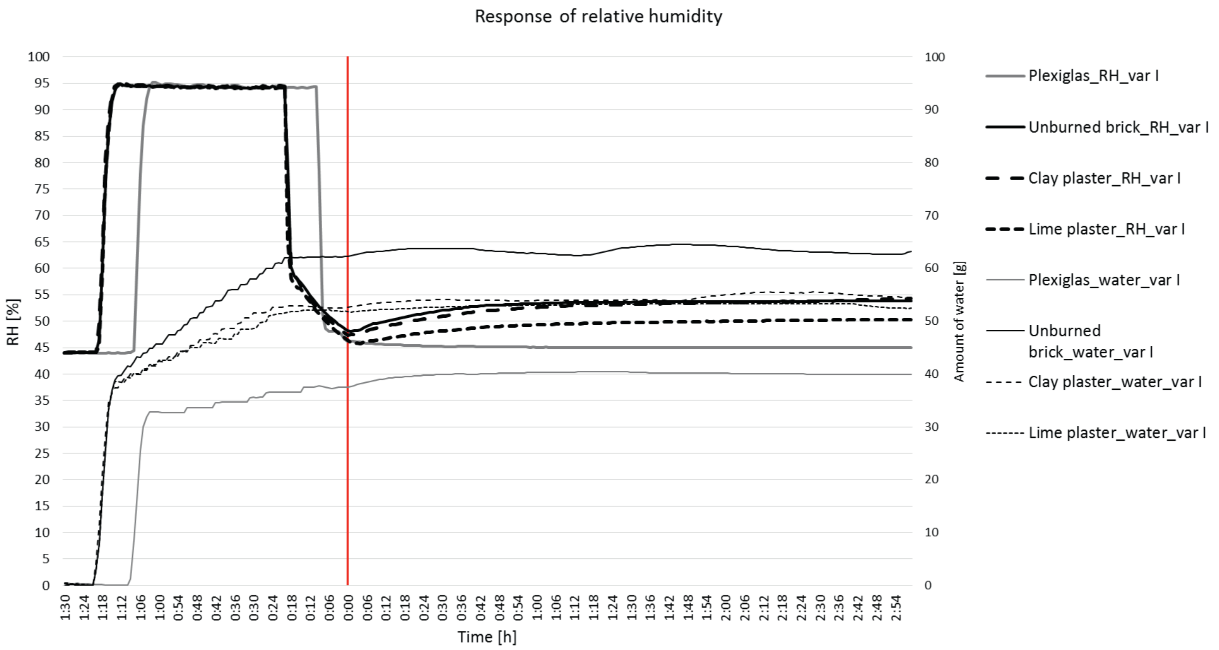


Fig. 5 Behaviour of test walls during dynamic desorption test

Conclusion

The methodology developed within the project was found sufficient for this kind of assessment. Also the results are valuable for further research in this field and proved that using so called "environmental active" materials can help to keep quality of internal microclimate and to reduce operating energy.

Acknowledgements

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