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Energy Procedia 132 (2017) 105–110

Energy Procedia

www.elsevier.com/locate/procedia

11th Nordic Symposium on Building Physics, NSB2017, 11-14 June 2017, Trondheim, Norway

Design and performance assessment of building counter-walls integrating Moisture Buffering "active" devices

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Abstract

The use of building materials with high moisture buffering capacity is a well-recognized strategy to moderate the variation of indoor moisture loads. Many researchers investigated the ability and potential of finishing materials and furniture for the reduction of the amplitudes of indoor relative humidity by characterising their Moisture Buffering Value. Nevertheless, the recent and widespread building practice, which is increasingly trying to reduce the air permeability and thermal transmittance of the envelope, is likely to even worsening indoor humidity conditions, with consequences for durability of materials and inhabitants' comfort and health. Very performing materials are then needed to act as buffering and quickly dampen high moisture loads.

This paper proposes the design of a building internal counter wall equipped with an "active" moisture buffering device. This is able to measure the indoor relative humidity and consequently increase the adsorbing capacity of a porous material through an air-flow. Experimental activities were carried out on different prototypes with the combination of granular Sepiolite with two different pore structures and nonwoven fabrics.

The devices effectiveness in terms of MBV has been dynamically tested in a climate chamber according to the DTU Nordtest method. Different "activation" times against several humidity levels were set in order to assess the best solution in different scenarios.

Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics.

Keywords: Moisture Buffering; Porous Material; Sepiolite; Humidity Control

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Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics
10.1016/j.egypro.2017.09.652

1. Introduction

Actual building practices, according to national energy efficiency regulations, are increasingly trying to reduce the envelope air permeability and thermal transmittance to reach high heating energy savings. The risk is to worsening the indoor humidity conditions, with consequences for durability of materials and inhabitants' comfort and health [1]. To account for the reduction in natural infiltration in buildings, efforts are being made to control indoor moisture. The use of building materials with high moisture buffering (MB) capacity is a well-recognized strategy to dampen indoor moisture loads. Interior finishing and furnishing materials with this hygroscopic performance are able to adsorb and desorb moisture from the adjacent air and can be used to control indoor humidity variations without additional energy costs [2]. Many studies investigate the hygrothermal properties of several materials used in building construction - cellular concrete, bricks, wood and wood-based materials [3–6] and cellulose insulation [7] - or in furnishings (textiles, wood and paper) [8]. To deal with the current "over-insulated" and tight building envelope, more and more performing materials are needed to rapidly adsorb the higher moisture loads. Nevertheless, traditional MB materials show some limitations, as the need of wide material surfaces interacting with the indoor environment [9] or hysteresis problems [10]. Furthermore, in the most recent new buildings the traditional finishing materials (already characterized by a good MB performance) are often replaced by dry construction technologies with poor hygroscopic properties.

As an alternative, the authors propose the use of a moisture buffering "active" device (MB-AD) able to measure the relative humidity indoors and control its high loads by forcing the air through a MB material using a low-energy fan system. The MB-AD can be part of an interior curtain-wall or an ornamental panel, like those used in buildings for noise insulation applications. In a previous paper [11], the authors presented the concept of the MB-AD, the arrangement of the equipment, control and activation systems, the experimental assessment of the Moisture Buffering Value.

This paper focuses on the results of a preliminary experimental characterization of the hygrometric properties of two typologies of Sepiolite, the adsorbent material included in the MB-AD. The consequent buffering performance (expressed by the Moisture Buffering Value) of the "active" device is evaluated and reported compared to "passive" material samples.

2. Material and methods

2.1. The counter-wall integrating the Moisture Buffering "active" device

The counter-wall integrating the moisture buffering "active" device, designed for building construction or retrofit, is composed by different functional elements. The main layer is the moisture buffering material which faces an interspace by means of suitable supporting structure. The interspace includes a fan system for the depressurization of the air inside it. When an RH sensor detects a predetermined value of relative humidity in the environment, the fan is activated and the interspace in contact with the buffer is depressurized, forcing the buffer to adsorb vapor interacting with the internal environment. Further details on the system working (fan power, activation system, humidity sensors) and figures are provided in a previous paper of the authors [11].

This study focuses on the MB performance of the adsorbent material selected for the MB-AD, which is Sepiolite, whose good hygrometric performance is assessed in several studies [11–14]. Sepiolite is a magnesium silicate having an internal structure of pores and channels with high adsorptive capacity for many gases and vapors [15,16]. Sepiolite can be found in the market in small grains. This paper investigates Sepiolite with two grains sizes:

- SEP30/60, corresponding to a ASTM index of 30/60 (minimum diameter of particles: 0,6 mm)
- SEP60/100, corresponding to a ASTM index of 60/100 (minimum diameter of particles: 0,25 mm).

A nonwoven fabric (maximum opens size of 100 μm) was used to encapsulate the granular Sepiolite.

Pore structure and sorption isotherms of the adsorbent material were assessed, while the calculation of the Moisture Buffering Value (MBV) was performed on the whole MB-AD.

2.2. Hygrometric characterization of Sepiolite

Total porosity and porous distribution of Sepiolite was measured by a mercury intrusion porosimeter (Micromeritics Autopore III) [17] according to the ASTM D4404 standard [18]. Specimens were dried at 60°C before the test in order to eliminate the influence of the water.

The isothermal sorption curves were obtained by measuring the moisture content of Sepiolite specimens in accordance with standard UNI EN ISO 12571 [19]. Specimens were dried in an oven at 65°C until a stable mass was reached. They were then placed in desiccators with saturated salt solutions to reach three relative humidity levels: 33% ($MgCl_2$), 75% (NaCl) and 93% (KNO_3). The test room temperature was maintained at 23°C. The moisture content was measured when samples reached the equilibrium inside each desiccators.

2.3. MBV of the Moisture Buffering "active" device through NORDTEST protocol

To evaluate the MB performance of active device included into the counter-wall, the MBV (g/(m^2%RH)) was assessed according to the Nordtest protocol developed by the Technical University of Denmark [20].

To this aim, 12 small prototypes were built: 6 "active" devices and 6 "passive" devices. For each typology both Sepiolite grain sizes were tested: SEP30/60 and SEP60/100. Sepiolite was put into plastic containers with a single free interface surface (A=0,0256 m^2) to ensure one-dimensional moisture flow towards the climate chamber's environment. The exchange surface was closed with the nonwoven fabric and a perforated aluminum sheet (1 mm thick) for the containment of the grains. The thickness of the adsorbent material was 90 mm (Fig. 1a). In the MB-AD (Fig. 1b), on the back of the container, a fan connected to the activation system was placed.

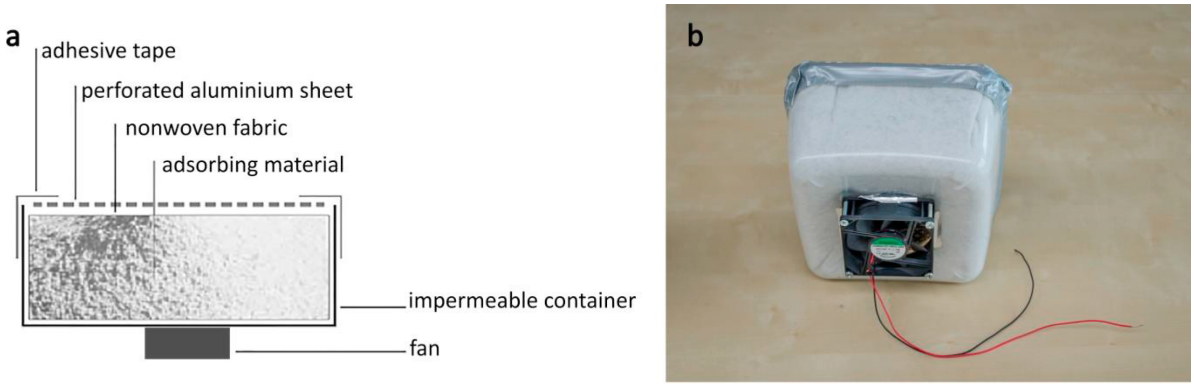

Fig. 1. (a) Cross-section of the prototype of MB-AD; (b) Fan positioned on the back of the container of the "active" samples.

Concerning the "active" devices, different RH% threshold for the activation were tested:

- Prototype A1 (fan activated during 33% RH condition)
- Prototype A2 (fan activated during 75% RH condition)
- Prototype A3 (fan always activated).

3 samples of "passive" devices (without depressurization of the interspaces), for each Sepiolite grain size, were assessed for comparison purposes: P1, P2, P3. Specimens were preconditioned for 120h at a constant temperature of 23°C and 50% RH, until they reached an equilibrium condition and then dynamically tested in a climate chamber (accuracy of ±3%RH and ±0.5°C) at the typical tests settings of Nordtest protocol: relative humidity cycles (8h at 75% RH and 16h at 33%) and constant temperature (23°C). The MBV was calculated on the basis of the average of the last 3 stable cycles (the weight amplitude did not vary by more than 5% from one day to the following one).

3. Results

3.1. Results of the hygrometric characterization of Sepiolite

Table 1 shows the results of the porosimeter analysis for both Sepiolite typologies. Even if total porosity of SEP30/60 specimens (53,44%) is a bit higher than SEP60/100 (51,36%), the total pore area of SPE60/100 is considerably higher. As a consequence, the larger surface area gives to SEP60/100 a higher adsorbing capacity.

Table 1. Results of the porosimeter analysis for both Sepiolite grain size.

Property	SEP30/60	SEP60/100
Density [kg/m^3]	713,4	711,3
Mean pore diameter [µm]	0,08 - 0,4	0,06 - 0,2
Total pore area [m^2/g]	6,15	15,84
Total porosity [%]	53,44	51,36
Effective porosity [m^3/m^3]	0,17	0,33

The performance of Sepiolite as humidity buffer is given by the amount of water that it is able to retain or liberate with the variations of temperature and the RH of adjacent air. The amounts of water retained by Sepiolite samples can be predicted analysing the sorption isotherm curves reported in Fig. 2. their trend for both typologies shows a large increase in water uptake at high relative humidity. Consequently, Sepiolite can be considered a suitable material to be used as controller of humidity in environments where the RH is usually very high. SEP60/100 shows a higher adsorbing capability than SEP30/60. The amount of water vapor retained by Sepiolite at about 90% RH level is about 0,23÷0,27 g/g. Results are in line with those previously found by the study of Caturla et al. [14].

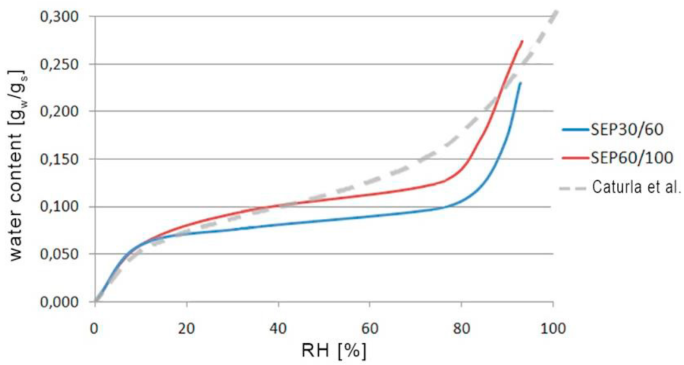

Fig. 2. Sorption Isotherm curves of the studied Sepiolite typologies, also compared with a previous study [14].

3.2. Results of the dynamic exposure test

Fig. 3 shows the measured water content in the passive and active samples, with both Sepiolite typologies, during the uptake and release cycles in the climatic chamber according to Nordtest protocol. Concerning the "passive" devices, the mean water content among the samples was calculated, and refers to "P" sample in the figures. The weight change of Sepiolite has a similar trend for both passive and active devices: it obviously increases during the adsorption phase and decreases during the desorption ones. Furthermore, there is a progressive weight gain during the first 9 cycles, after which a stable condition is reached.

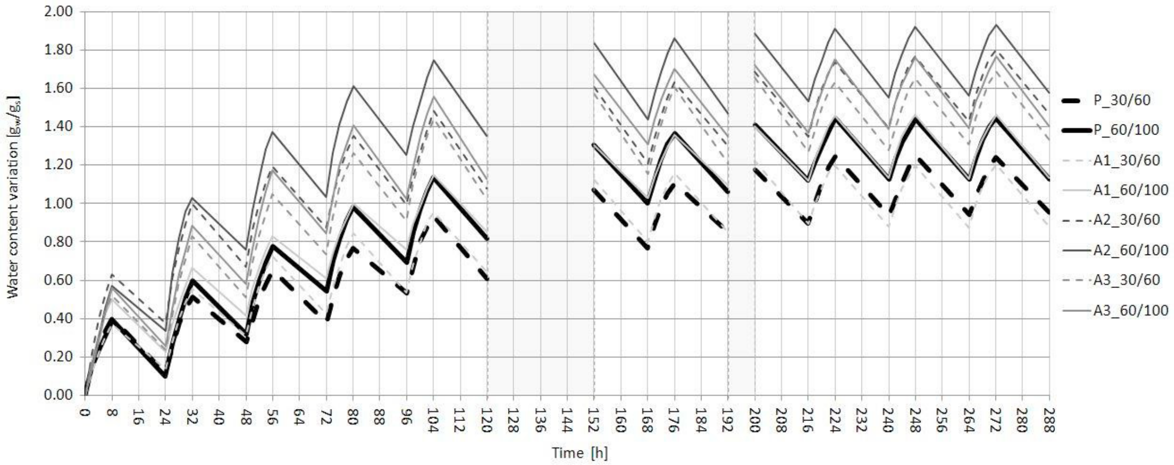

Fig. 3. Moisture uptake and release cycles for passive and active device samples from dynamic measurements. Missing data in blank spaces are due to the inaccessibility of the laboratories.

It can be noted that, for both Sepiolite granulometries, the passive devices P and the active A1 (33%) show similar values. The continuous activation of the fan in prototype A1 (sorption and desorption phases) factually limits its hygrometric performance. On the contrary prototypes A2 (75%) and A3 (33% and 75%), which have the fan working during the adsorption phases (while they release water naturally during the desorption phases), adsorb and desorb a higher quantity of moisture. The weight gain of A2 and A3 samples, compared to initial weight, at the end of 75% RH phase, is respectively about 1,75% and 1,65% for SEP30/60 and about 1,91% and 1,76% for SEP60/100.

The presence of possible "hysteretic phenomena" was assessed by considering the moisture mass inside the specimens after the desorption phase. In Fig. 4a, the quantity of adsorbed and desorbed moisture during test cycles is shown. It can be noticed that after 9 cycles Sepiolite can release all the amount of water absorbed and therefore to maintain its sorption properties, with a negligible hysteretic effect. In fact, in the last daily cycles, samples adsorb and desorb approximately the same quantity of moisture (less than 1g), without losing their adsorbing capacity.

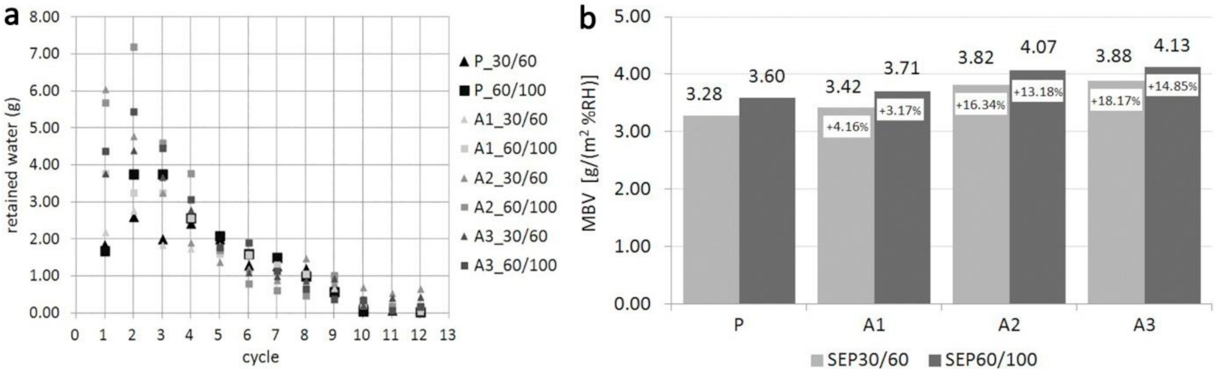

Fig. 4. (a) Amount of water retained by samples at the end of each cycle; (b) MBV [g/(m^2·%RH)] for the tested active and passive devices.

Fig. 4b shows the average MBV [g/(m^2·%RH)] for the tested passive and active samples over the last three stable cycles. Sepiolite in passive devices (P) already has a very good performance (3,28<MBV<3,60 g/(m^2·%RH)). Better results are achieved in the active devices and for the highest RH activations. In particular, the activation system in sample A3-SEP60/100 increases the MB performance of the corresponding passive sample of about 14,85% (MBV up to 4,13 [g/(m^2·%RH)]). As also anticipated by the sorption isotherms trends, Sepiolite SEP60/100 exhibits a higher moisture buffering capacity than Sepiolite SEP30/60.

4. Conclusion

This study demonstrates how Sepiolite exhibits an optimum absorption capacity without noticeable hysteresis phenomena (especially with the smallest granulometry) and can be considered as a good material for MB applications in buildings.

According to the classification of the MB materials in the Nordtest project, all the samples analyzed in this work can be considered with an "excellent" performance (MBV>2 g/(m2%RH), higher than almost all traditional building materials and similar to "desiccant" materials.

The use of Sepiolite in "active" devices further enhance the MB performance of passive samples of about 15% and could represent an effective application to reduce the moisture buffering exposed area usually needed by traditional buffering materials to dampen indoor RH% variations. Furthermore, the limited performance of the A1 samples allows to exclude a "continuous" working of the fans applied in the MB-AD. The activation can be limited to the phases of higher indoor relative humidity loads (adsorption phases), detected by the specific RH sensor, thus limiting the energy consumptions, which are already quite low, as demonstrated in [11]. Further researches through field measurements are desirable to verify the performance of the MB-AD to dampen humidity loads in real conditions.

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