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Moisture buffering “active” devices for indoor humidity control: preliminary experimental evaluations

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Abstract

In recent building practice, obligations of legislation relating to Nearly Zero Energy Buildings (NZEB) (European Directives 2002/91/EC and 2010/31/EU) are carried out mainly by high thermal resistance and total air tightness of the envelope, in order to minimize heat dispersions by conduction and infiltration as much as possible. These measures cause new ways of heat and moisture exchange in the building envelope and are likely to create high internal moisture load with consequences for durability of materials and inhabitants’ comfort and health. Improvement in the thermal performance of the envelope can then lead to the paradoxical need for high energy consumption in order to handle the vapor peaks indoors by using mechanical ventilation equipments. Even if with HVAC devices it is possible to provide an acceptable indoor climate, there is still a need to develop more passive and less energy intensive methods to moderate the indoor environment in NZEB.

In recent decades many authors have focused on a promising strategy related to the use of “moisture buffering” materials which dampen indoor humidity variations without additional energy costs. Nevertheless, many internal finishing materials commonly used at present are still not highly performant or lead to problems of hysteresis.

In the present study, we propose an alternative solution, which is the design of a moisture buffering “active” device, to be integrated in a part of the building envelope, which is able to measure the relative humidity indoors and control its loads by a low-energy-consumption fan system. The humidity control performance of the device has been dynamically tested in a climate chamber and has been compared with traditional “passive” material samples in order to measure the Moisture Buffering Value (MBV) according to the DTU test method.

Experimental results showed that “passive” samples have high moisture buffering values [MBV = 6.12 g/($m^2 \cdot \%$ RH)] and do not lead to hysteresis phenomena. The MBV measured in the “active” devices increased up to 29%, which predicts promising future applications for low-energy-consumption indoor humidity control.

Selection and peer-review under responsibility of KES International

Keywords: Moisture Buffering; Active Envelope; Humidity Control; Energy Saving, NZEB

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1. Introduction

The thermal performance of the building envelope is central to the debate on the construction of "Nearly Zero Energy Buildings", as required by the recent Energy Performance of Buildings Directive 2002/91/EC [1] and its recast [2].

The relationship between the type of envelope and final energy consumptions is usually translated into a simplistic deduction, i.e., in order to ensure that the energy consumption of a building is close to zero, it is primarily necessary to dissipate very low heat during the cold season. A global building thermal resistance and air tightness is therefore one of the most important prerequisites to achieve "nearly zero energy".

Consequently, several countries have increased their air tightness and thermal resistance requirements in buildings, and the construction market is always more oriented towards "overinsulated" lightweight envelopes and a global reduction in the air permeability of windows. Also renovation techniques aim to obtain the same prerequisites, for instance by replacing single glazed windows by new very tight double or triple glazed windows, or by adding interior or exterior insulation.

Buildings are more and more conceived as "airtight boxes", both as a result of reduced permeability of the envelopes and windows, and due to the diffusion of plasters, materials for interior coverings and paintings with poor hygroscopic properties, but fast and economic application. These measures, in combination with an unsuitable ventilation strategy, risk to bring about higher moisture loads.

Interior moisture loads in a building can strongly affect indoor humidity levels [3]. Along with surface temperatures, these could cause condensation on interior surfaces, material defacement and proliferation of microorganisms with consequences on human comfort and health [4].

For the typical range of relative humidity and air temperature likely to be found in homes, the drop in temperature that will trigger condensation is around 1–5 K [5]. Condensation is therefore a potential problem for any dwelling in which relatively high daytime indoor temperature and relative humidity (caused by indoor human activities) are followed by a temperature drop at night. The 80% RH value next to the surface stated by IEA [6] for mould growth may seem quite high given that typical indoor RH levels will range from roughly 20% to 60%. However, relative humidity values in the air adjacent to a surface are strongly affected by air circulation within the space and temperature of the adjacent surface.

To account for the reduction in natural infiltration in buildings, efforts are being made to increase moisture source control measures, educate homeowners on controlling indoor moisture, and to integrate mechanical ventilation in new houses.

Nevertheless, equipments for the management of internal moisture load may have considerable costs both in the installation phase as well as during their use. Besides, their installation is not always possible in old buildings. So even if with HVAC devices it is possible to provide acceptable indoor climate, nevertheless, there is a need to develop more passive and less energy intensive methods in order to moderate the indoor environment.

A promising strategy, which acts directly on internal finishing, is related to the use of "moisture buffering" (MB) materials which dampen indoor humidity variations.

The "moisture buffering" effect is known as the capacity of the interior finishing and furnishing materials to moderate indoor humidity in buildings, thanks to their hygroscopic ability. Moisture buffering materials are able to adsorb and desorb moisture from the adjacent air and can be used to control indoor humidity variations without additional energy costs [7].

Several authors stress the importance of moisture buffering in the managing interior humidity, supported by measurements [8,9] and simulations [7,10,11]. Researchers have shown that several materials used in building construction - cellular concrete, bricks, wood and wood-based materials [12–15] and cellulose insulation [16] - or in furnishings (textiles, wood and paper) [17] show moisture buffering behavior.

Nevertheless, as moisture buffering phenomenon involves only the external layers of a finishing material, it is necessary that the materials have very high humidity control performance. Many internal finishing materials commonly used at present still show problems of hysteresis [8].

We propose then the design of a moisture buffering "active" device, to be integrated in a part of the building envelope, obtained by the optimization of the moisture buffering capability of a porous natural mineral (sepiolite). The "active" device is able to measure the relative humidity indoors and control its high loads by a low-energy-consumption fan system.

In this paper, we report the preliminary assessments for the construction of the moisture buffering "active" device (MB-AD), and in particular:

- construction of a set of control and activation sensors;
- experimental evaluation of the Moisture Buffering Value according to the DTU test method [18] of the MB-AD, and comparison with "passive" material samples.

These assessments are necessary prior to the optimization of the design of the building component and the construction of a real-scale device for testing under ambient conditions.

Nomenclature

A	Area	m^2
MBV	Moisture Buffering Value	$g/(m^2\cdot\% RH)$
RH	Relative Humidity	%
t	Time	h
T	Temperature	K
m	Weight	g

2. Methodology

2.1. Description of the moisture buffering active device (MB-AD)

The MB-AD is configured as an "interior wall panel" for building construction or retrofit, which consists of different functional layers (Fig. 1).

The main layer is the moisture buffer, which is able to adsorb and release vapor interacting with the internal environment. This buffering layer is positioned to face an interspace by means of suitable supporting layers. The interspace is closed by a fan system for the depressurization of the air inside it. The fan is connected to RH sensors by means of an electronic framework.

When RH indoor, detected by the sensors, exceeds a predetermined value, the fan is activated and the interspace in contact with the buffer is depressurized, forcing the buffer to adsorb water and consequently reducing the vapor within the environment.

The moisture buffering material chosen for the preliminary tests is sepiolite. It is a magnesium silicate of fibrous morphology with fine microporous channels running parallel to the length of the fibers. The structural characteristics of sepiolite, its fibrous habit and small channels are responsible for its absorption and desorption properties and the derived applications. The water adsorption isotherm of sepiolite shows a large increase in water uptake at high relative humidity. Consequently, this material is useful as controller of humidity in environments where the RH is usually very high. The amount of water vapor retained by sepiolite at 100% RH is of the order of 0.3–0.5 g/g [19–21].

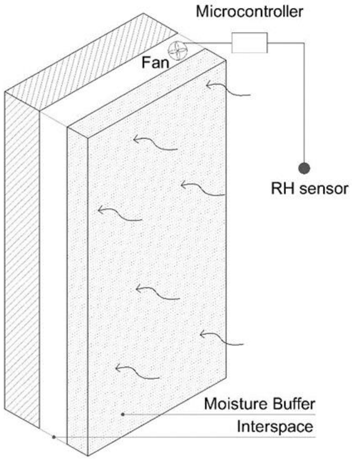

Fig. 1. Operation scheme of the interior wall panel with the MB-AD

The fan used for the depressurization of the interspace facing the moisture buffer is an axial fan with low DC voltage (12V), with dimensions of 80x80x25 mm, flow rate of 67 m^3/hour and absorbed current of 0.15 A. The fan power is very low (1.8 W) resulting in limited energy consumptions.

The control and activation system of the active device was realized through the open source framework for electronic prototyping called "Arduino".

The humidity sensor used is Honeywell HIH-4030, which measures the RH (%) and returns an analog output signal with a linear response, with an accuracy of +/- 3.5%. A microcontroller via transistor allows the activation / deactivation of the fan in the interspace, for a given value of RH measured in the environment (Fig. 2).

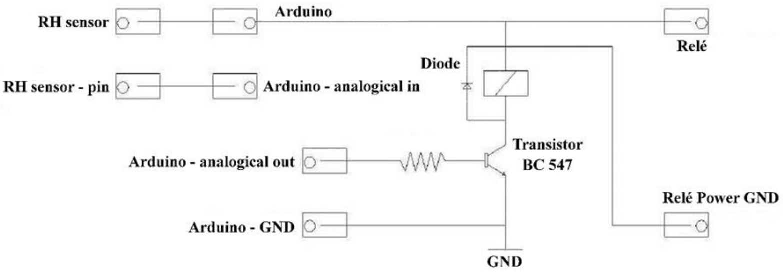

Fig. 2. Connection scheme between the RH sensor, the open source framework for electronic prototyping "Arduino", and the microcontroller via transistor for the activation / deactivation of the fan

2.2. Characterization tests of the active device for its moisture buffering performance

The NORDTEST project's report developed by the Technical University of Denmark (DTU) [18] describes a standardized quantity to practically characterize the moisture buffering capacity of materials (Moisture Buffering Value) and a test protocol, which expresses how the moisture buffering of materials should be tested. The practical Moisture Buffer Value (or simply MBV) indicates the amount of water that is transported in or out of a material per open surface area during a certain period of time when it is subjected to variations in relative humidity of the surrounding air. The moisture exchange during the period is reported per open surface area and per % RH variation. The unit for MBV is then g/(m2·% RH).

The protocol states that the practical MBV is determined in an experimental set up where the sample is exposed to cyclic step-changes in RH between high and low values for 8 and 16 hours (h), respectively. The typical periodical exposure for the test is of 8h at 75% RH and 16h at 33%, the size of the RH-interval will then be 42% RH.

The MBV is a direct measure of the amount of moisture transported to and from a material when the exposure is given.

According to the NORDTEST protocol, MB-AD was dynamically tested in a climate chamber in the laboratory of the Università Politecnica delle Marche and compared with "passive" samples. The controlled exposure cycle was 8h at 75% RH and 16h at 33%, a run time that corresponds to that of typical exposure in practice – typically a daily variation.

The objective was to determine the effectiveness of the adsorbent material chosen (sepiolite) in the case of its "passive" or "active" use (by forcing the passage of air inside it, through depressurization of the adjacent interspace).

In this regard, 3 small prototypes of each type of device (active or passive) were built. Sealing of edges and backsides of the prototypes were needed to ensure one-dimensional moisture flow and a defined exposure area for the specimens.

Plastic containers (195 mm x 195 mm, total surface A=0,0380 m^2) were used at this aim for the outer casing of the prototypes, in order to leave a single free interface surface between the moisture buffer and the environment of the climate chamber. A perforated aluminum sheet (1 mm thick) for the containment of sepiolite delimits the free surface of the casing that is 160 mm x 160 mm (excluding the sealing tape), totaling A=0.0256 m^2 (larger than the minimum value suggested by the protocol of A=0.0100 m^2).

The total moisture buffer thickness inside the container was 90 mm (Fig. 3).

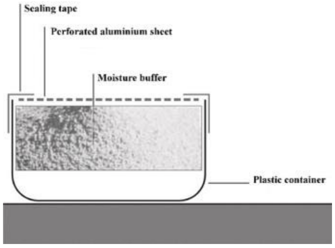

Fig. 3. Schematic cross-section of the moisture buffering "passive" device

In the MB-AD, on the back of the container, a fan connected to the activation system was placed. As such, the prototypes analyzed were overall:

- 3 samples of MB-AD, each with a different RH% threshold for the activation:
    - Prototype B1 (fan activated when RH exceeds 33%)
    - Prototype B2 (fan activated when RH exceeds 60%)
    - Prototype B3 (fan activated when RH exceeds 70%)
- 3 samples of the "passive" device (without depressurization of the interspace): A1, A2, A3.

Concerning prototype B1, the threshold chosen for the activation of the fan was 33% RH, which is the lowest limit of the periodical exposure foreseen by the NORDTEST protocol. In this way, the mechanism of depressurization of the interspace was always kept in operation.

Regarding prototype B2, the RH threshold chosen was the typical value indicated as reference for comfort [22]. Finally, for prototype B3, the critical threshold for the development of typical mold of residential buildings was considered (Aspergillus versicolor, Penicillium chrysogenum, Stachybotrys chartarum).

Fig. 4 shows the connection between the RH sensors, the framework "Arduino", and the 3 MB-AD.

The operation of the climate chamber was controlled by a software, which managed the cycles of exposure and monitoring of indoor environmental conditions. Table 1 shows the experimental tests settings.

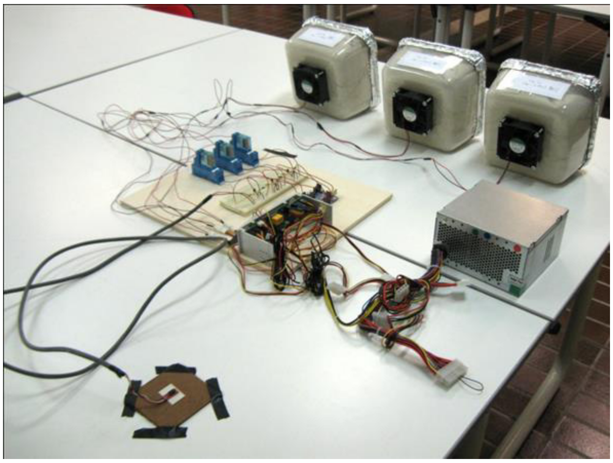

Fig. 4. Connection between the RH sensors, the framework "Arduino", and the 3 MB-AD

The humidity control of the chamber works by supplying it with either humid or dry air in an intermittent mode, such that the desired humidity in the chamber is achieved. Progressive changes in RH in the climate chamber were not obtained instantaneously, but it took about 10 minutes (transition period), which was still in accordance with the requirements of the NORDTEST Protocol (accuracy of ±3% RH within at the most 30 minutes after the intended change). The temperature was kept within 23 ± 0.5 K.

The specimens, before being subjected to the progressive variations between 33% and 75% RH at constant temperature (23 K), were preconditioned at a temperature of 23 K and RH of 50% for 120h, until they reached an equilibrium condition. At regular intervals during the cyclic exposure in the climate chamber, the weight of the specimens was measured with an analytical balance (resolution 0.1 g).

The protocol requires that the specimen be weighed at least 5 times in the adsorption phase and at least once before and once after each exposure period within one cycle. Therefore, we scheduled 5 measurements during the adsorption phase and another one at the end of the desorption phase.

Table 1. Experimental test settings in the climate chamber

Exposure period	24 h
Number of cycles of exposure	5
High RH (%) exposure (adsorption phase)	75%
Duration of high RH exposure	8 h
Low RH (%) exposure (desorption phase)	33%

Duration of low RH exposure	16 h
Duration of transition 33-75% RH	About 10 min
Duration of transition 75-33% RH	About 10 min

The weight was measured in the laboratory where the temperature was equal to that of the climate chamber with a tolerance of ± 2 K.

During each cycle, the change in the weight of the specimens (Δm) was determined as the average between:

- The weight gain (moisture uptake) during the adsorption phase (8 hours): $\Delta m_{adsorb} = m_{8h}-m_0$;
- The weight loss during the desorption phase (16 hours): $\Delta m_{desorb} = m_{24h}-m_{8h}$.

The Moisture Buffering Value is the value of Δm (normalized with respect to the exposed surface and the variation of RH) calculated on the basis of the average of at least 3 stable cycles (the weight amplitude must not vary by more than 5% from one day to the next).

3. Results

The possibility of using sepiolite as controller of humidity is given by the amount of water that is able to retain or liberate when the temperature and the RH of air is changed during a given time.

The amounts of water retained by each sample is predicted by the so-called "sorption isotherm".

In an ambient with a certain RH and T, a porous building material after a while will reach an equilibrium condition with the environment. The sorption isotherm establishes the relationship between the moisture content in a porous body, RH and T. The route of RH can be traced from dry to wet or from wet to dry. The former is called adsorption, the latter desorption. The difference between adsorption and desorption is referred to as "hygroscopic hysteresis".

Fig. 5 shows the measured weight change response of the moisture buffer in passive devices A1, A2, A3 and their average values. Fig. 6 shows the measured weight change response of the moisture buffer in MB-AD B1, B2, B3, also compared with the average value of the measured weight change trend in the passive devices. The set of results of Figs. 5 and 6 indicates that when the RH of air changes, the sepiolite liberates or retains water reversibly.

The weight change of sepiolite, in both passive and active devices, shows a similar trend, which obviously increases during the adsorption phase and decreases during the desorption ones. In other words, the sepiolite acts as a humidity controller of the environment by retaining an amount of water according to the initial and final RH.

The determination of the mass of moisture that remains in the specimen at the end of the desorption phase enables to evaluate the presence of "hysteretic phenomena". In this sense the sepiolite is able to discharge all the amount of water absorbed and therefore to maintain its sorption properties, without manifesting hysteresis phenomena.

Active devices B2 and B3, which had the working fan during the adsorption phases, accumulated more water compared to the average amount gathered by the passive devices. The active device B1, which had the continuously running fan all throughout the exposure conditions, showed an opposite behavior, that is a reduced storage capacity of the moisture buffer.

In prototypes B2 and B3, the activation of the fan exclusively influences the adsorption phase, so they release water naturally during the desorption phase, as in the case of the passive samples. In prototype B1, the continuous activation of the fan influences the hygrometric performance of the material during the whole measurement period, sorption and desorption phases. In particular, it makes B1 operating in accordance with a different sorption isotherm, as, at the same RH, it is able to retain and release a lower amount of water.

Therefore, we can exclude a "continuous" working of the active device applied in the wall panel. The activation of the fans in the MB-AD should be limited to the phases of high indoor relative humidity loads, detected by the specific sensor. In any case, even if we consider the fan working 8h daily, the consequent annual energy consumption will be very low, around 5 kWh.

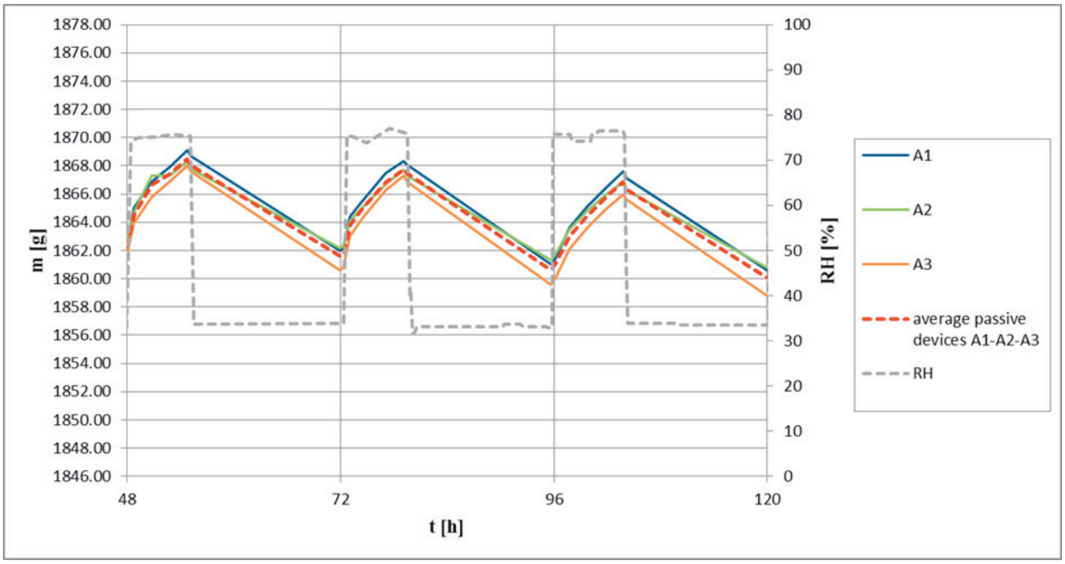

Fig. 5. Moisture uptake and release cycles for the three passive device samples A1, A2, A3 and their average values. Exposure between 33 and 75% RH during the last 3 stable cycles

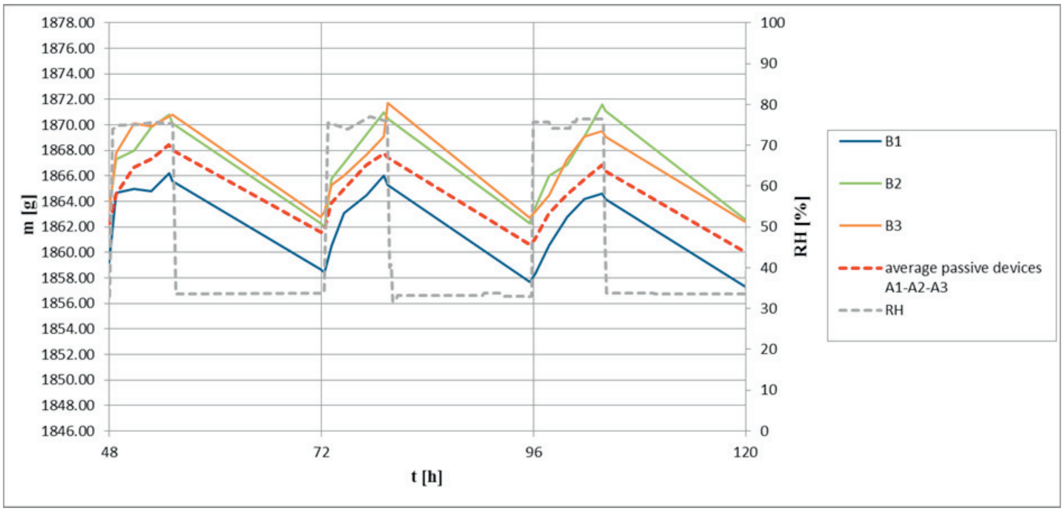

Fig. 6. Moisture uptake and release cycles for the three active device samples B1, B2, B3, also compared with the average value of the mass trend of the passive device. Exposure between 33 and 75% RH during the last 3 stable cycles

Fig. 7 shows the average MBV [g/(m^2·% RH)] for the different active and passive devices tested. The weight change is normalized as mass change per m^2 and ΔRH to give the practical MBV. For the passive device, the average value for the three specimens is provided.

Experimental results showed that the sepiolite in the "passive" devices has high MBV values (6.12 g/(m^2·% RH). The MBV measured in the MB-AD B2 and B3 increased by about 29% and 22% (until 7.91 m^2·% RH for B2) respectively, predicting good applications of the filter in an "active" device for low-power indoor humidity control in the future.

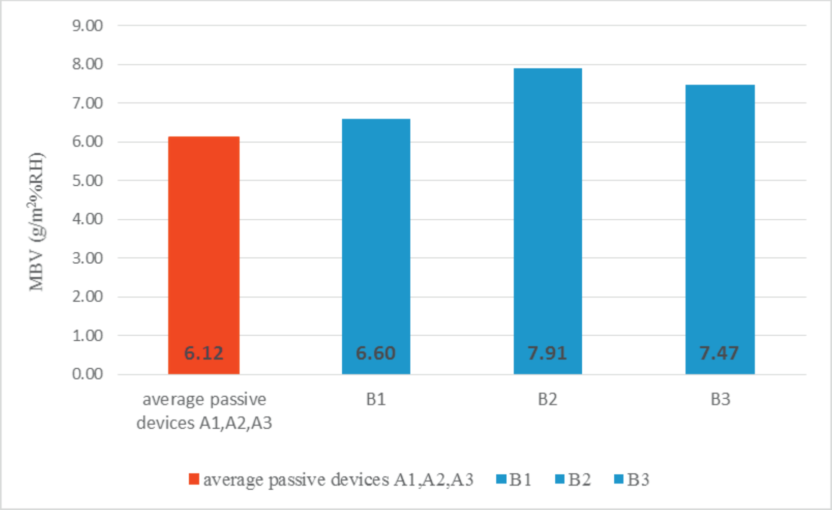

Fig. 7. MBV [g/(m^2·% RH)] for the different active and passive devices. Each bar indicates the average of the MBV over the last three stable cycles

4. Conclusions

If we consider the classification of the moisture buffering materials in the context of the NORDTEST project [18], in both types of device (passive and active), sepiolite can be considered as an "excellent" moisture buffer (MBV > 2 g/(m^2·% RH), with high absorption capacity and without creating problems of hysteresis.

The "active" device is able to further optimize the functioning of the buffer material, increasing its adsorption capacity by up to 29% when the fans are activated for the depressurization of the air cavity for high loads of RH indoors. The possibility to use the MB-AD active device, integrated in a part of the building envelope, to dampen indoor RH% variations could actually allow to reduce the moisture buffering exposed area usually needed by traditional buffering materials.

Further research is required to improve the design and operation of the MB-AD. In particular, improvement is needed to:

- design the containment components of the buffer material and the depressurized cavity;
- optimize the size of the buffer material in relation to adsorption needs in different types and sizes of indoor environments;
- define the method of assembly, installation and subsequent maintenance/replacement of components of the wall-panel.

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