Numerical Evaluation of Moisture Buffering Capacity of Different Inner Casing

Enrico Baschieri – Ecodesign s.r.l., Scandiano, Italy – baschieri@ecodesign.it
Anne Friederike Goy – Ecodesign s.r.l., Scandiano, Italy – goy@ecodesign.it

Abstract

How does the moisture buffering capacity of the inner casing vary, according to the degree of the relative humidity of the room? Can a "rule of thumb" be obtained from a numerical simulation of a case study? A numerical evaluation of a heavyweight building was run in order to estimate the different moisture buffering capacity of two different kinds of plasters. In this study, the environmental data of a room, calculated using a dynamic simulation, was integrated with the hygroscopic properties of the materials obtained from the archives of the software WUFI, in order to simulate the variation of the relative humidity of a room inside a nearly Zero Energy Building with a mechanical ventilation with heat recovery.

1. Introduction

The microclimate within a room is affected by several factors, such as the relative humidity, the heat sources, the ventilation and the presence of hygroscopic materials. As observed in the literature (e.g., Eckermann and Ziegert, 2006; Eshrar et al., 2015; Svennberg, 2006), the influence of the materials is manifested in the effects of thermal accumulation of the masses and in the effect of hygroscopic accumulation of porous materials overlooking the indoor air. The hygroscopic capacity of a room consists in the ability of the materials facing the internal air to moderate changes of the internal relative humidity. The moisture buffering function of internal casing is a passive system to reduce the fluctuations of indoor humidity. This humidity has a major influence on the internal comfort (Ronzino, 2014).
With this study we have investigated the moisture buffering value of two different casings in order to estimate the effect of finishing materials on indoor relative humidity and, indirectly, on comfort.

2. Moisture Buffering Capacity

2.1 Hygroscopic Properties of Building Materials from UNI EN ISO 12571

2.1.1 Absorption as function of Relative Humidity

The moisture absorption and release of construction materials is strictly dependent on the relative humidity degree of the air inside a room (Fig. 1).

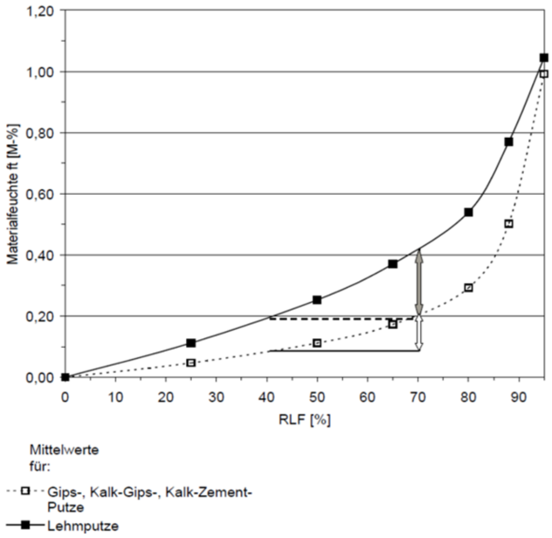

Fig. 1 – Absorption/Relative Humidity (UNI EN ISO 12571:2013)

2.1.2 Humidity absorption/release

The UNI EN ISO 12571:2013 reports the moisture absorption and release test curves of several materials. Fig. 2, for instance, depicts the experimental curves obtained for some materials, showing very different behaviours. In this case, experimental data were obtained in a test room, first increasing the relative humidity at a constant temperature from 50 to 80% and then, after 12 hours, reducing it to 50%.

Part of
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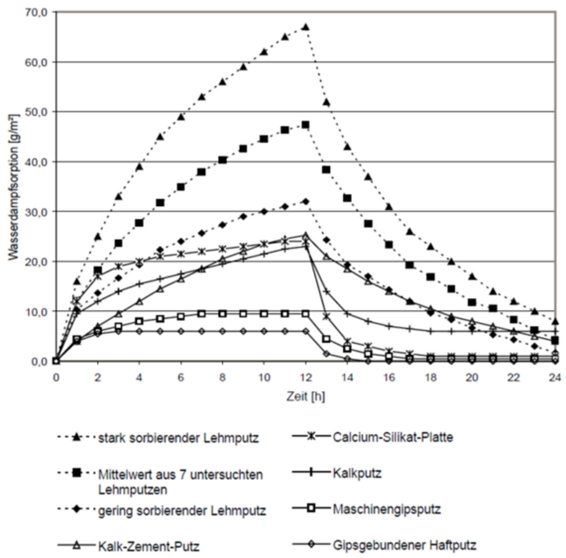

Fig. 2 – Humidity Absorption/Release (UNI EN ISO 12571:2013)

2.2 Ideal Moisture Buffer Value

The moisture buffering capacity is a property of materials, which can be described using the ideal Moisture Buffer Value. The MBV_{ideal} is defined as the exchange of moisture g(t) normalized on the variation of RH of the surface ΔRH:

$$MBV_{ideal} \approx \frac{g(t)}{\Delta \mathrm{RH}} = 0{,}00568 \times \mathrm{b_m} \times \Delta \mathrm{p_v} \times \sqrt{t_\mathrm{p}} \quad \left[\frac{\mathrm{kg}}{(\mathrm{m}^2\%\mathrm{UR})}\right] \tag{1}$$

Where:

- $g(t)$: Moisture flux $[kg/\,m^2\,s]$
- $\Delta \mathrm{RH}$: Relative Humidity variation [%]
- $\mathrm{b_m}$: Moisture effusivity $[\frac{kg}{m^2 Pa\sqrt{s}}]$
- $\Delta \mathrm{p_s}$: Saturation vapour pressure variation [Pa]
- t_p: Period [s]

The ideal Moisture Buffer Value formula was taken from Carsten Rode et al. (2003, 2006).

2.3 Practical Moisture Buffer Value

The Moisture Buffer Value (MBV) indicates the amount of moisture that is absorbed or released by the material, per square meter of exchange surface, during a certain period of time when it is subject to a specific variation of the RH of the indoor air, at a specific speed of the internal air. The MBV_{ideal} is derived from the hygroscopic properties of the material and is a property of the material itself, in contrast to the $MBV_{practical}$, which is experimentally measured, and includes also the effect of moisture resistance of the film-air surface, while the surface resistance is assumed to be equal to zero in the formula of the MBV_{ideal}.

Due to this simplification, the values of the calculated MBV of some materials are about three times larger than the measured values. The MBV estimates in a reliable way the moisture buffering capacity of building materials only when it is closely linked to the relative humidity rate of the room. For this reason, only one value of MBV is not enough to describe the moisture buffering capacity of building materials.

3. Case study

3.1 Indoor Environment

Starting from the results of the dynamic simulation of the environmental data of a sample room, run with the software Tas Engineering (ESDL, 2019), we investigated the moisture buffering capacity (MBV_{ideal}) of two different kinds of plasters (hydraulic lime plaster and clay plaster) in order to measure their ability to adjust the indoor relative humidity.

Our test room was a kitchen-dining room of 35.10 m^2, with 77.83 m^2 of plastered walls and ceiling, a net volume of 94.78 m^3, with variable ventilation regime between day and night of 8.55 - 17.11 m^3/h, equal to 0.09-0.18 ach, and an infiltration rate of about 0.06 ach at atmospheric pressure.

The indoor environment of our sample room is described in the following graphs.

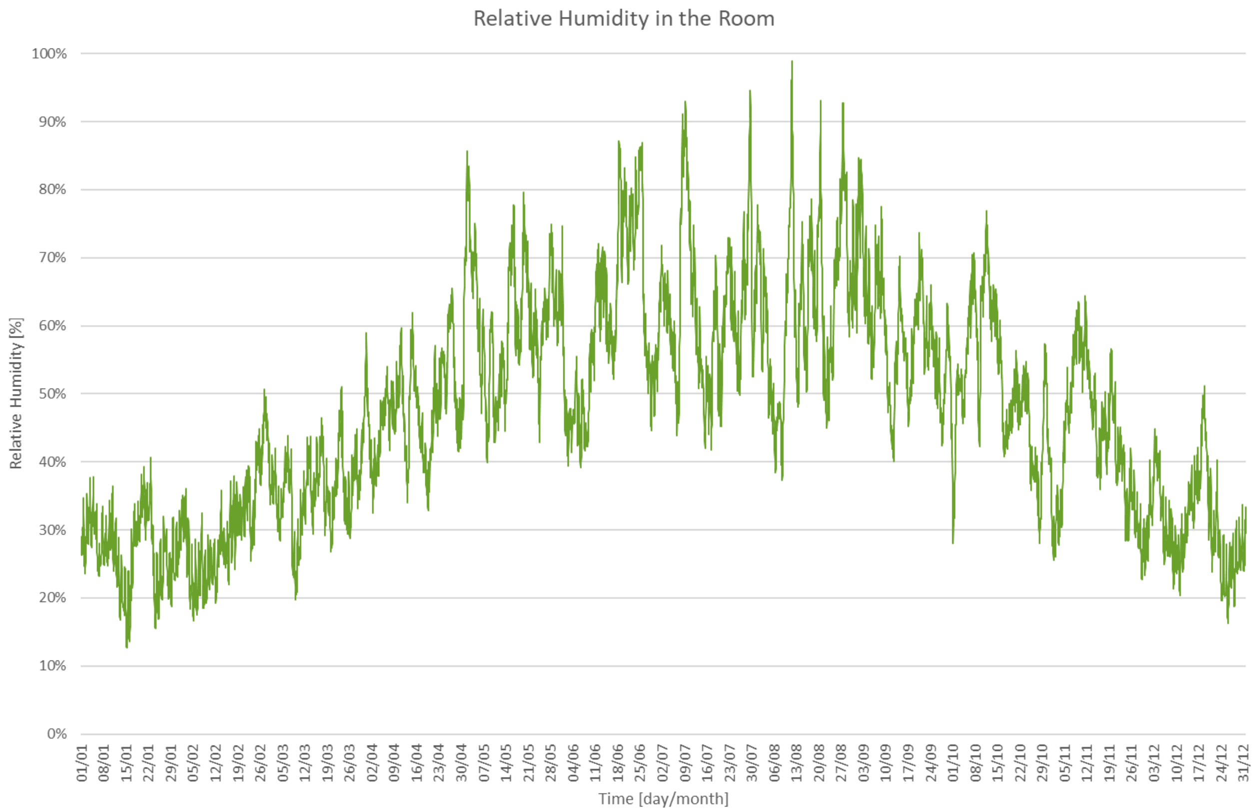

Fig. 3 – Relative Humidity of the room

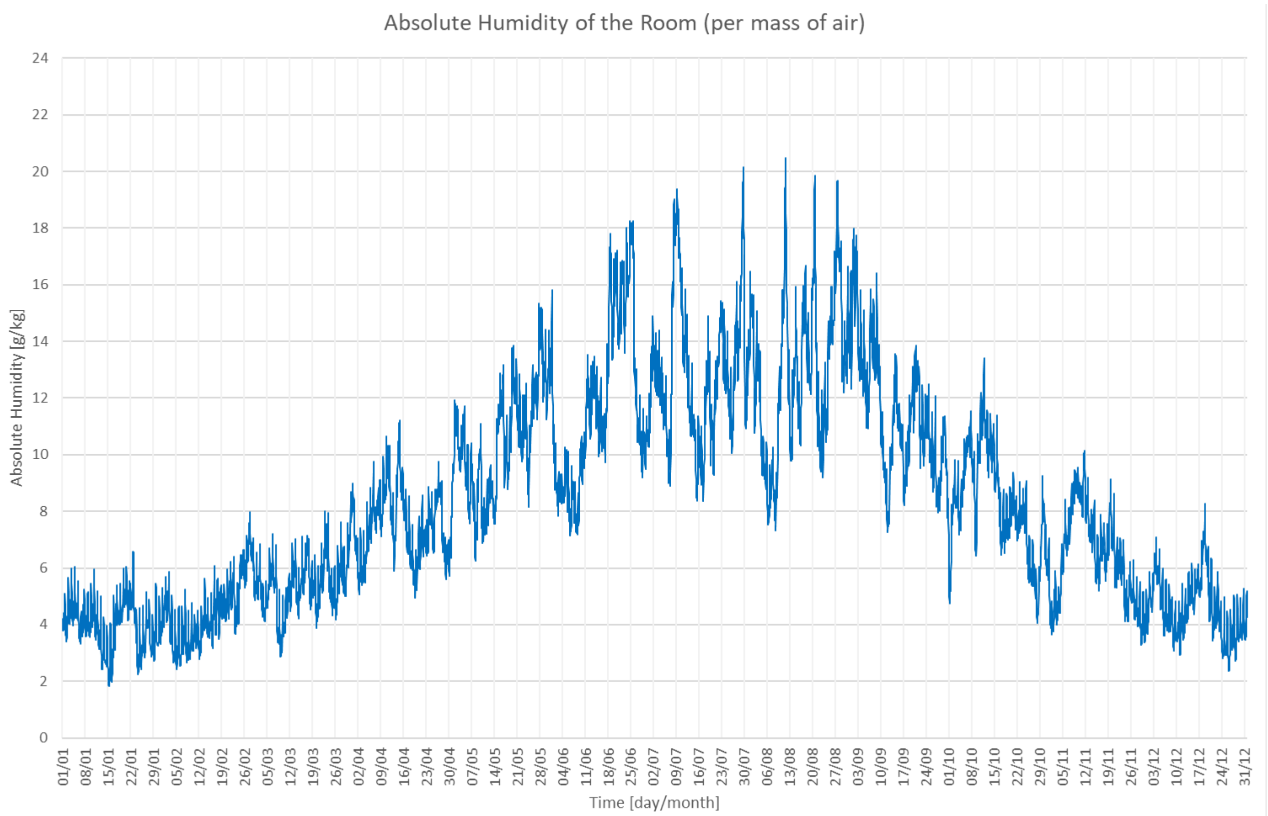

Fig. 4 – Absolute Humidity of the room (per mass of air)

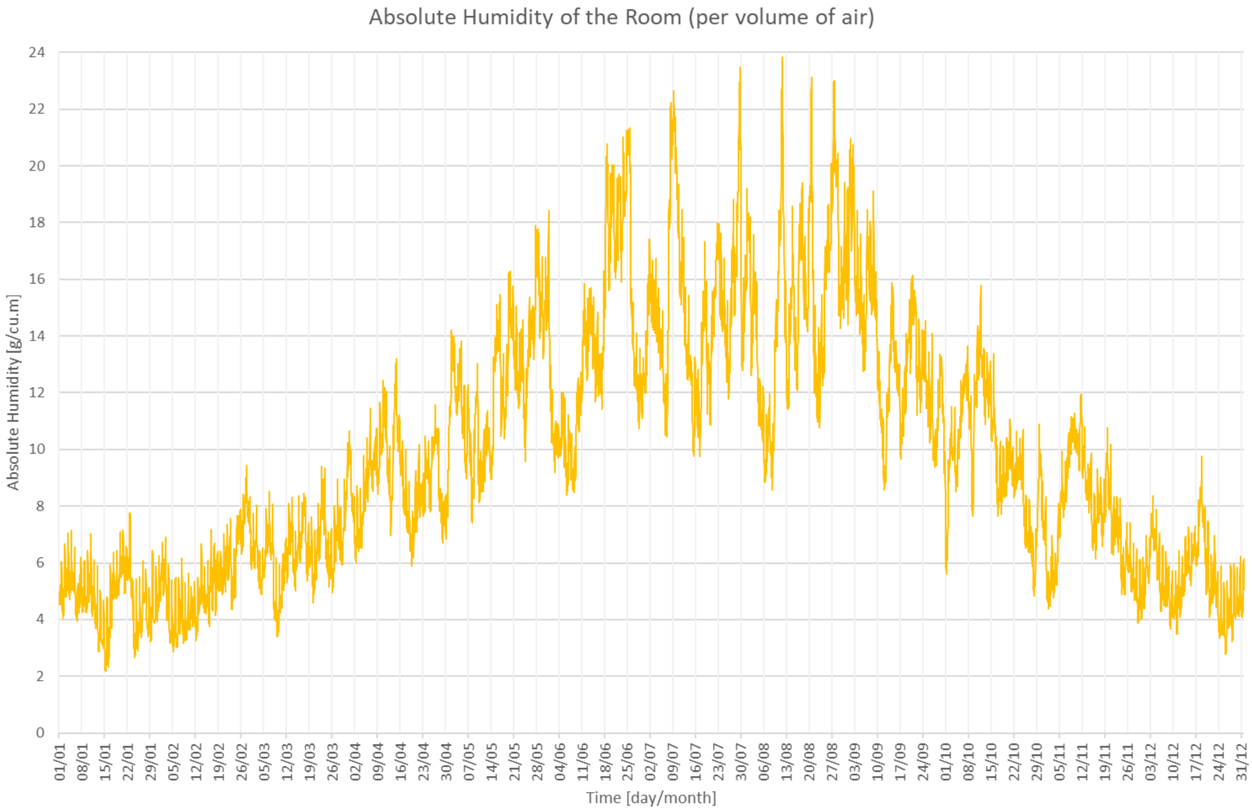

Fig. 5 – Absolute Humidity of the room (per volume of air)

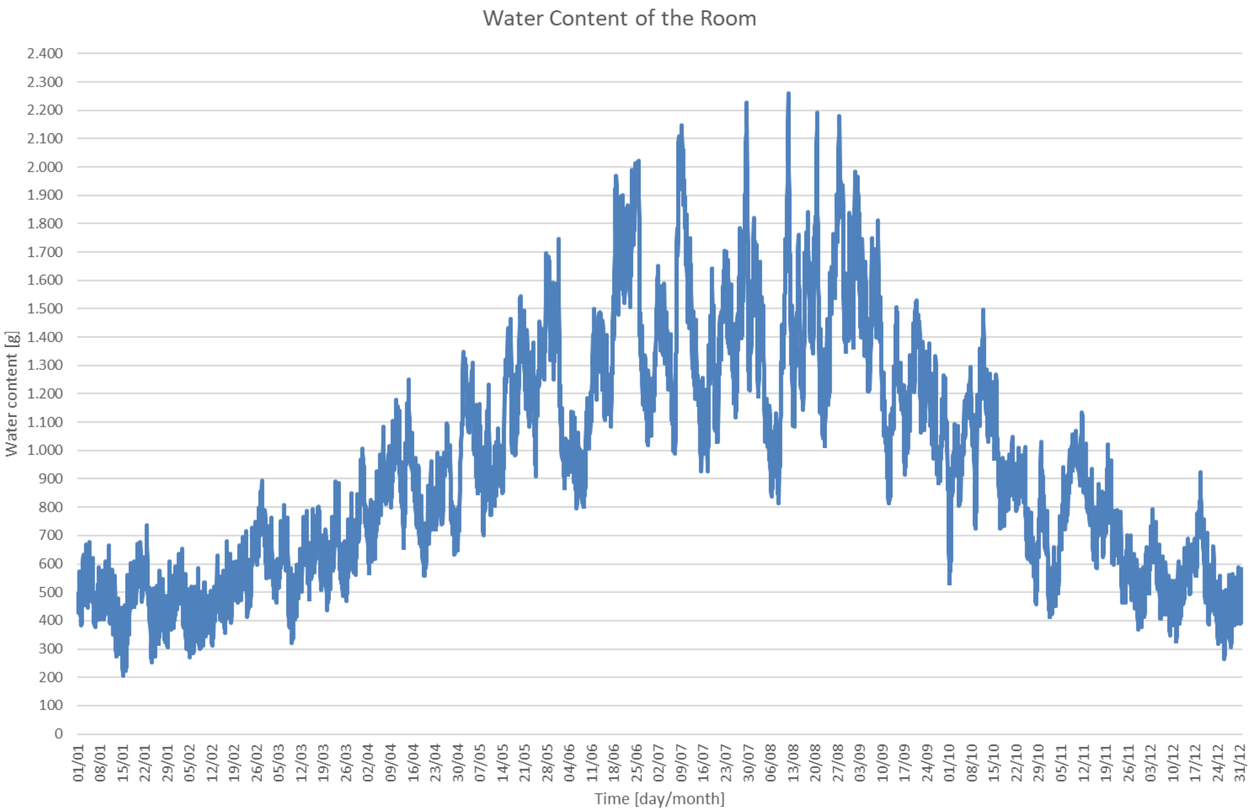

Fig. 6 – Moisture content of the room

3.2 Plaster Moisture Storage Functions

The experimental values of the original moisture storage curves, taken from the software WUFI, were streamlined between the given points to obtain a Moisture Buffering Capacity value for each tenth of percentage point of relative humidity, in order to have the same accuracy of the dynamic simulation data (Fig.s 7, 8, 9, 10).

The streamlined curves were used in Excel to calculate the MBV_{ideal} for each hour, taking in to account the relative humidity values and hourly variations calculated with the dynamic simulation.

Table 1 – Hydraulic lime plaster parameters from WUFI

Bulk density	kg/m³	1830.0
Porosity	m³/m³	0.27
Specific Heat Capacity, Dry	J/kgK	850.0
Thermal Conductivity, Dry, 10°C	W/mK	0.7
Water Vapour Diffusion Resistance Factor	-	19.99
Reference Water Content	kg/m³	10.23
Free Water Saturation	kg/m³	211.03
Water Absorption Coefficient	kg/m²√s	0.067
Drying Factor	-	10
Moisture-dep. Thermal Cond. Supplement	%/M.-%	9.981
Typical Built-In Moisture	kg/m³	211.03
Temp-dep. Thermal Cond. Supplement	W/mK²	0.0002

Table 2 – Clay plaster parameters from WUFI

Bulk density	kg/m³	1568.0
Porosity	m³/m³	0.41
Specific Heat Capacity, Dry	J/kgK	488.0
Thermal Conductivity, Dry, 10 °C	W/mK	0.4837
Water Vapour Diffusion Resistance Factor	-	11.0
Reference Water Content	kg/m³	39.0
Free Water Saturation	kg/m³	375.0
Water Absorption Coefficient	kg/m²√s	0.183
Drying Factor	-	10
Moisture-dep. Thermal Cond. Supplement	%/M.-%	8.0
Typical Built-In Moisture	kg/m³	375.0
Temp-dep. Thermal Cond. Supplement	W/mK²	0.0002

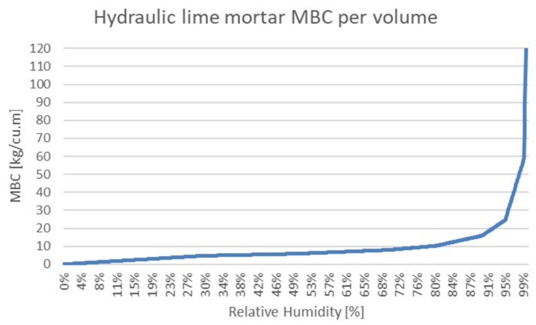

Fig. 7 – Moisture storage function of the hydraulic lime plaster

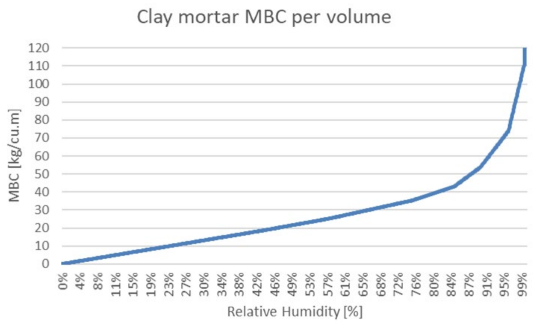

Fig. 8 – Moisture storage function of the clay plaster

The volumetric Moisture Buffering Capacity curves were used to derive the specific absorption curve, considering a plaster thickness of two centimeters.

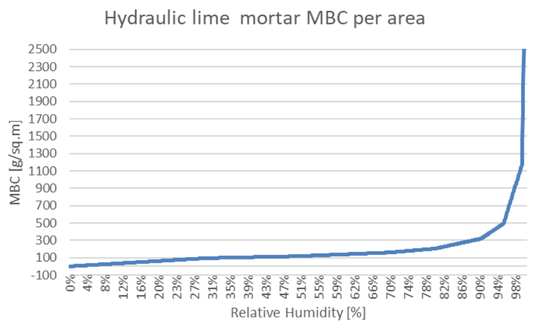

Fig. 9 – Moisture storage function of the hydraulic lime plaster per area

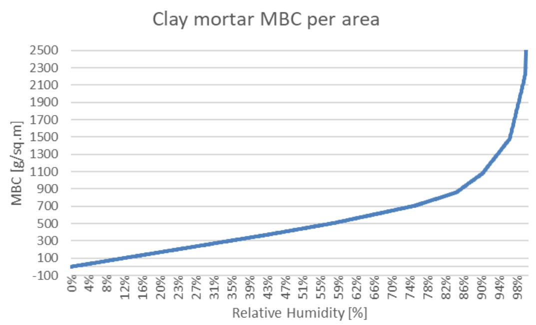

Fig. 10 – Moisture storage function of the clay plaster per area

3.3 Interaction Between Plaster and Relative Humidity

The moisture penetration depth in the plaster was calculated using the formula:

$$EMPD = \sqrt{\frac{\delta \times p_{s(\Theta)} \times T}{\rho\xi \times \pi}} \qquad (2)$$

Where:

- δ: Vapour permeably [kg/(m s Pa)]
- $p_{s(\Theta)}$: Saturation vapour pressure [Pa]
- T: Period [s]
- ρ: Dry mass [kg/mc]
- ξ: Hygroscopic capacity [kg/kg]
- π: Pi [-]

The formula of the moisture penetration depth was taken from: Cunningham (2003). The moisture penetration depth in the hydraulic lime plaster varies between 2.3-2.7 mm, with a peak of 1.5-3.5 mm, depending on the relative humidity of the room (Fig. 11).

The moisture penetration depth in the clay plaster varies between 1.5-2.5 mm, because of the greater absorption capacity of the clay, which tends to slow down the penetration capacity (Fig. 12).

First of all, we investigated the specific absorption/release of the two materials. The specific moisture absorption/release of the hydraulic lime plaster was about ±0.5 g/m^2 (Fig. 13). The specific moisture absorption/release of the clay plaster was about ±1.5 g/m^2, three times bigger than the hydraulic lime plaster (Fig. 14).

Following this, we investigated the absolute moisture absorption/release of the two plasters, considering their extension in the envelope of the whole room. We did not take in to account the MBD of other materials present in the room, such as wood floor, furniture, etc.

The hydraulic lime plaster was able to remove/add about 50 g of moisture from the room (Fig. 15).

The clay plaster was able to remove/add about 100-125 g of moisture from the room, about 2.0-2.5 times more than the hydraulic lime plaster (Fig. 16).

4. Mitigation Effects on the Room

Finally, we calculated the effect of this moisture absorption/release on the relative humidity of the room. The absorption/release effect was calculated taking in to account the variation of the relative humidity between two consecutive hours. A reduction of relative humidity in the room reduces the moisture absorption of the plaster (induces a moisture release), whereas an increase of relative humidity in the room stops the moisture release of the plaster (induces a moisture absorption).

4.1 Indoor Relative Humidity Variation

The indoor relative humidity variation changed with the two different kinds of plasters.

The hydraulic lime plaster was able to remove/add about 50 g of moisture from the room, varying the relative humidity by about ±2-3% (Fig. 17).

The clay plaster was able to remove/add about 100-120 g of moisture, varying the relative humidity of the room by about ±8-10% (Fig. 18).

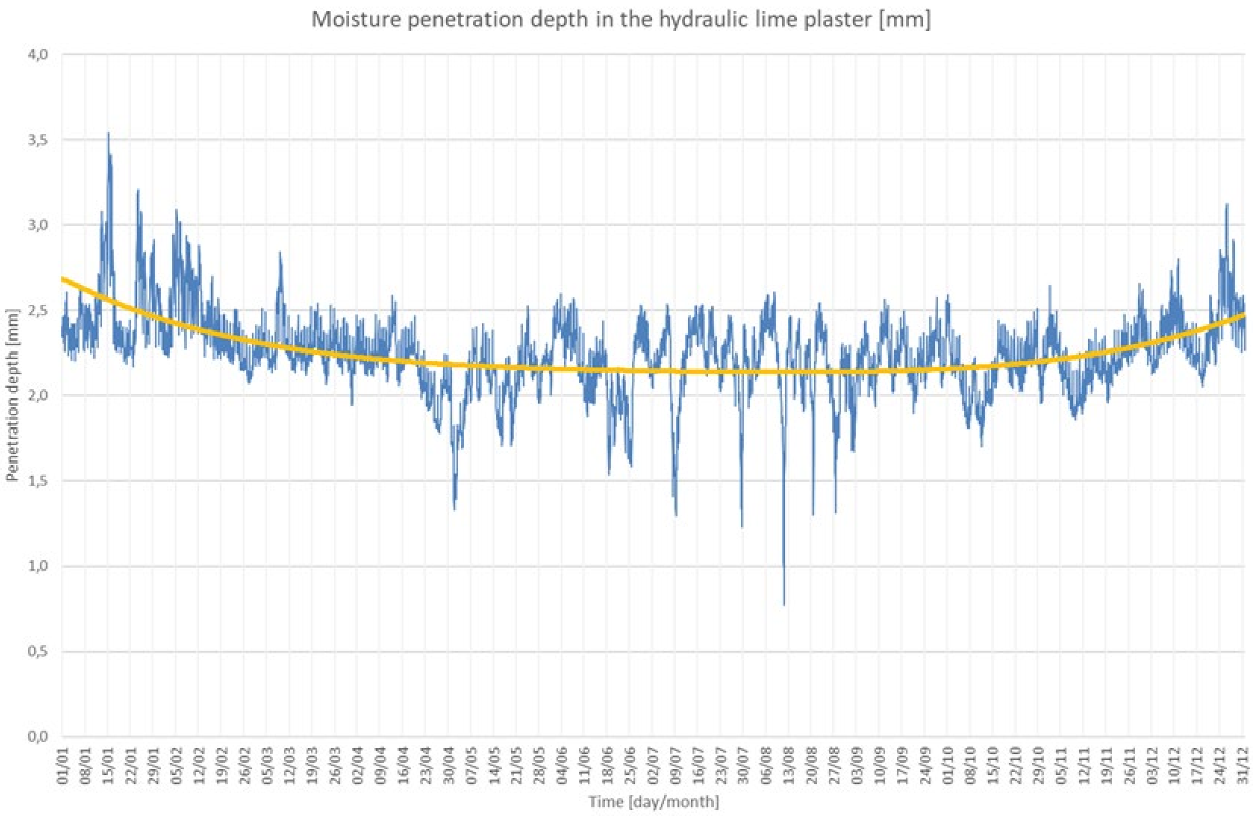

Fig. 11 – Moisture penetration depth in the hydraulic lime plaster

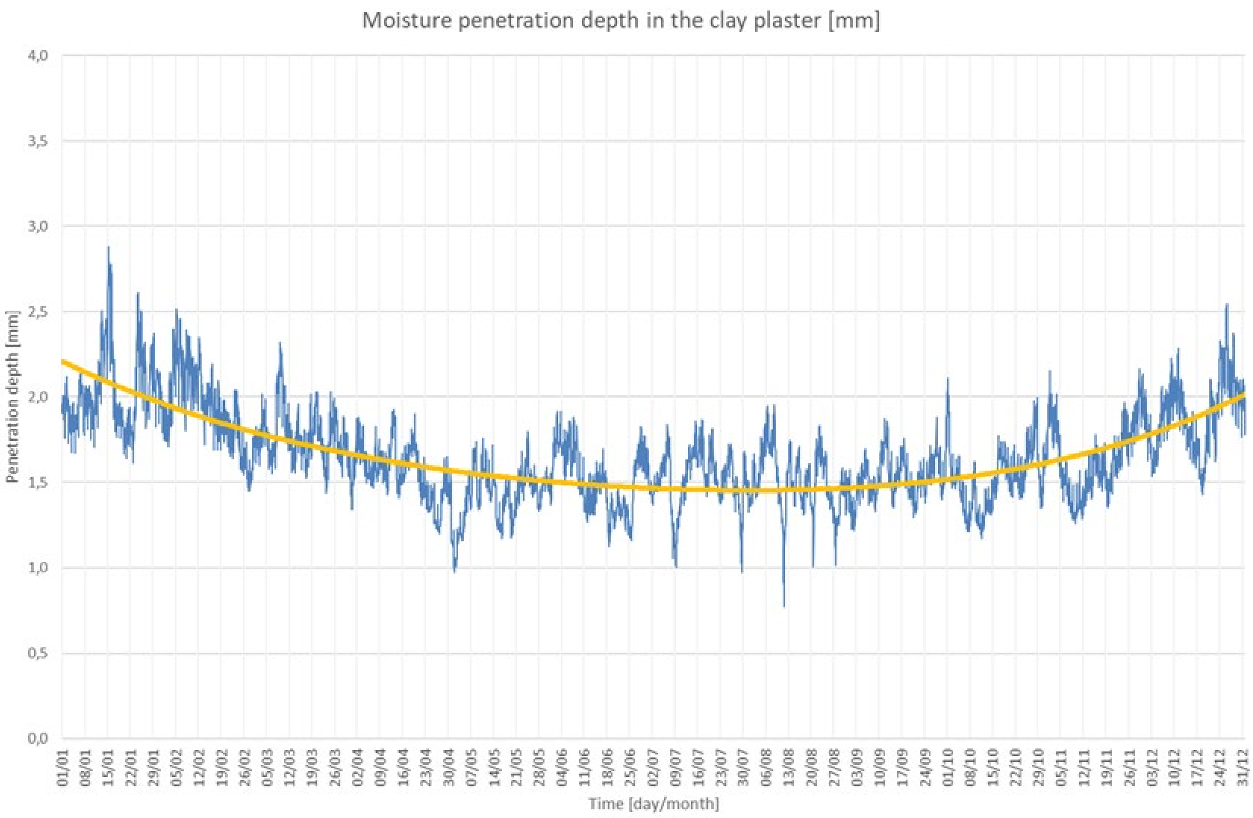

Fig. 12 – Moisture penetration depth in the clay plaster

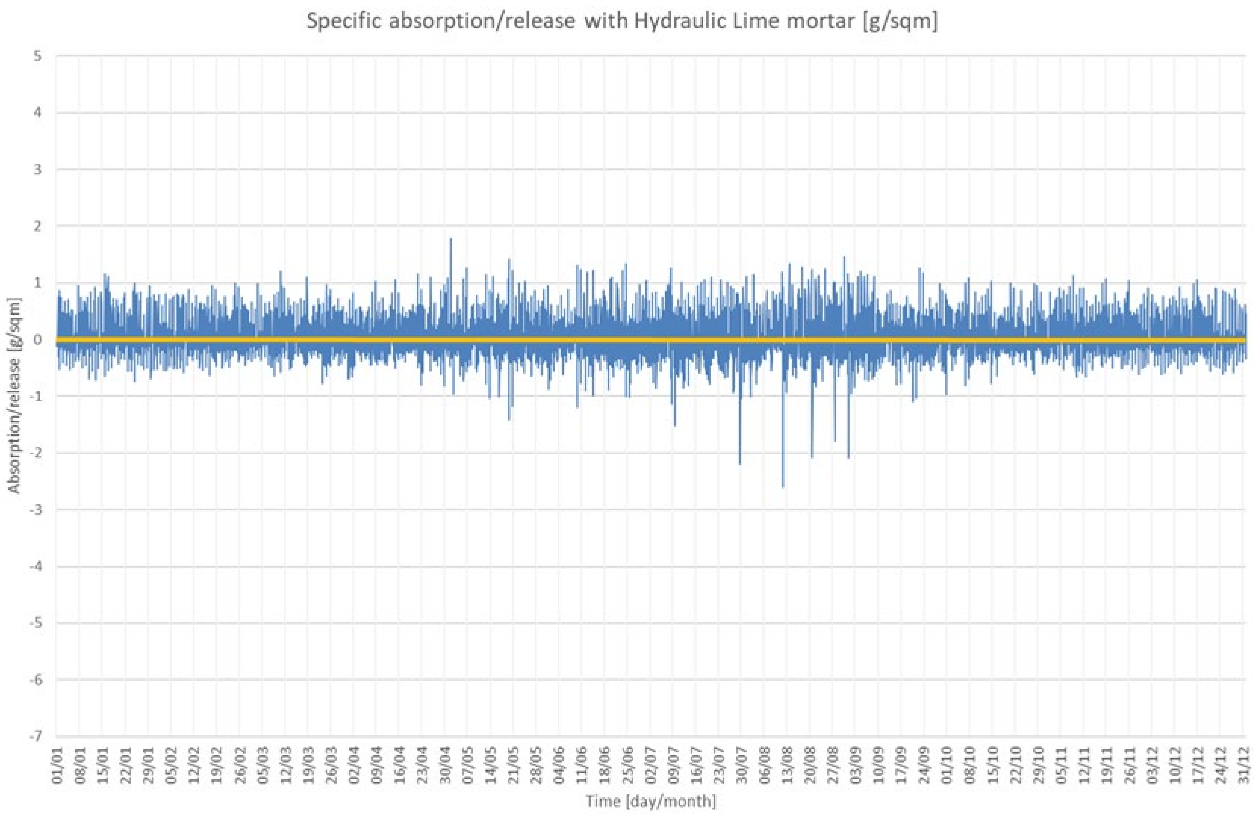

Fig. 13 – Specific absorption/release with Hydraulic Lime mortar

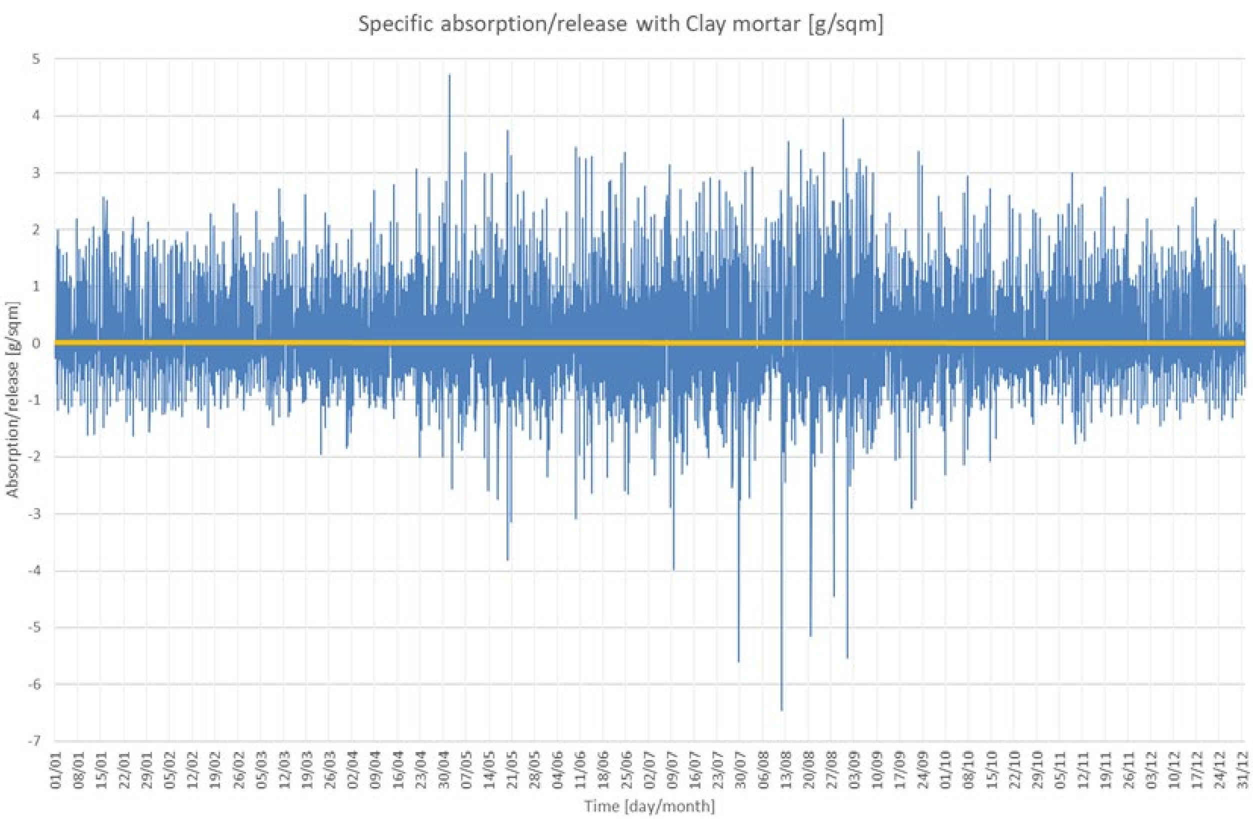

Fig. 14 – Specific absorption/release with Clay mortar

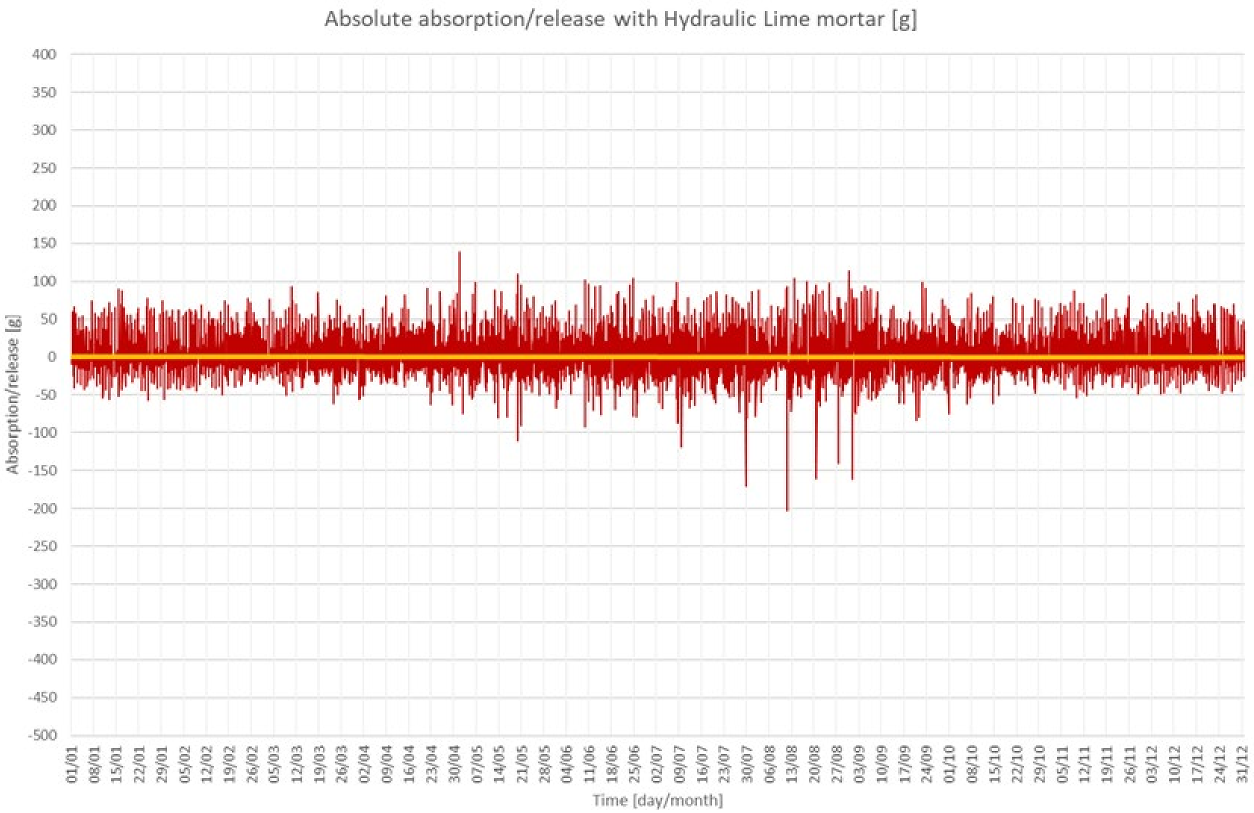

Fig. 15 – Absolute absorption/release with Hydraulic Lime mortar

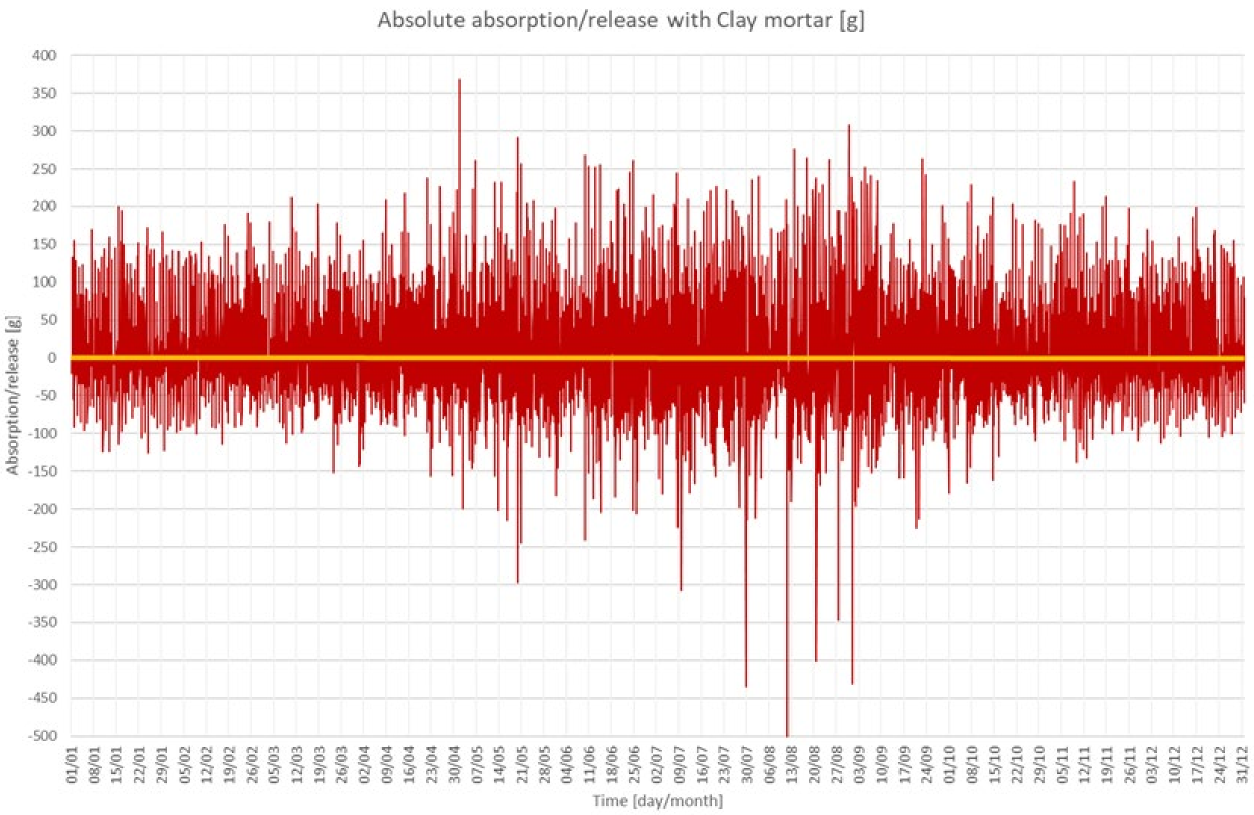

Fig. 16 – Absolute absorption/release with Clay mortar

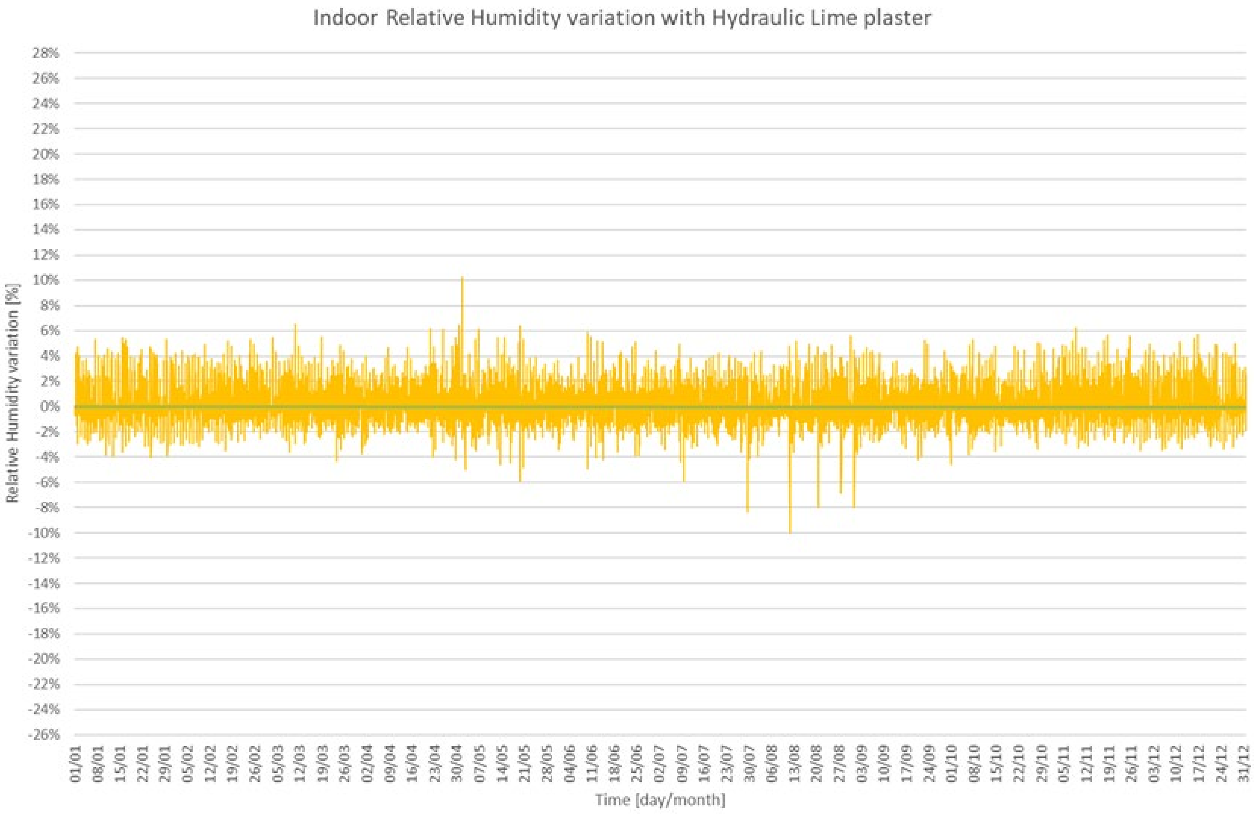

Fig. 17 – Indoor Relative Humidity with Hydraulic Lime plaster

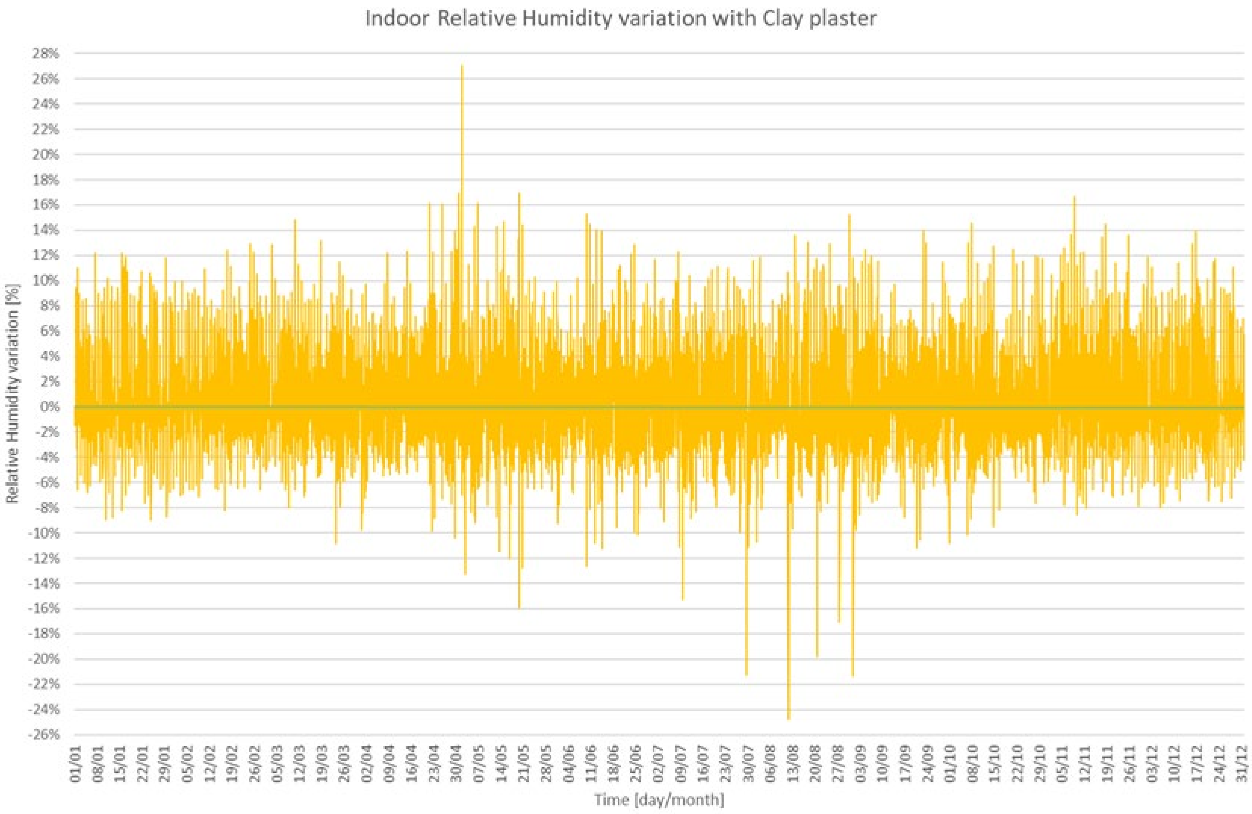

Fig. 18 – Indoor Relative Humidity with Clay plaster

5. Conclusions

The MBV is a parameter representative of the moisture buffering capacity of building materials, closely linked to the relative humidity rate of the internal air and to the analysed time period.
The moisture penetration depth, in the period of one hour, varies between 1 and 3.5 mm for both plasters, indicating the size of the reactive layer.
The Moisture Buffering Capacity of the finishing materials is able to correct the relative humidity of the room and can be used as passive strategy to adjust the interior relative humidity.
The moisture penetration depth is in the same order of measurement for both materials: 2.3-2.7 mm for the hydraulic lime plaster and 1.5-2.5 mm for the clay plaster.
The specific absorption/release is about ±0.5 g/m^2 for the hydraulic lime plaster and 1.5 g/m^2 for the clay plaster.
The hydraulic lime plaster is able to remove/add about 50 g of moisture from the room, varying the relative humidity by about ±2-3%.
The clay plaster is able to remove/add about 100-125 g of moisture, varying the relative humidity of the room by about ±8-10%.
The Moisture Buffer Value (MBV) is a parameter indicative of the hygroscopic capacity of building materials. It is closely linked to the content of the internal relative humidity of the room and the period analysed.
The penetration depth of the moisture in the plaster, in the range of one hour, varies between 1 mm and 3-3.5 mm for both the layers of plaster, giving us the size of the reactive layer of the plaster.
The indoor relative humidity of the room varies considerably depending on the type of plaster analysed. The clay plaster is able to remove/add about 2.0-2.5 times more moisture than the hydraulic lime plaster and is able to vary the relative humidity of the room in the same proportion.
The moisture buffering capacity of clay plaster is suitable to be used as a passive strategy to mitigate the fluctuations of indoor relative humidity, in lightweight and in heavyweight buildings, in order to improve internal comfort.

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