Hygroscopic and Thermal Inertia Impact of Biobased Insulation in a Wood Frame Wall

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Abstract. In this study, large scale experiments are performed with walls implemented in a climatic chamber in order to assess either the hygroscopic impact or the thermal phase shift of flexible bio-based insulating materials and clay panels. The conditions are set to be as close as possible to the field. Before the large scale tests, the materials are characterized individually with moisture-buffering, sorption-desorption and water vapour permeability tests.

The aim of the first part is to assess the moisture buffering ability of a flexible bio-based insulating material set behind a OSB board. Conventional mineral wool (rock wool) is set inside wall n°1 and flax is set inside wall n°2. The outer side of the chamber is set at T = 5 °C/RH = 80% in order to simulate winter climate. The inner side of the chamber is set at T = 23 °C and different variations of water relative humidity between 40–95% are applied. The results show that the hygroscopic impact of the insulating material set behind a OSB is very limited. The inner relative humidity is mostly absorbed and released by the OSB board that acted both as water vapor barrier and moisture buffer. Characterizations and real tests show that the moisture buffering capacity of clay is slightly higher than gypsum.

In the second part, summer thermal phase shifts tests are performed with either conventional mineral wool or wood wool, and either gypsum or clay inner panels. In the outer side of the chamber temperature cycles of 24 h are applied (T = 15–40–15 °C). The temperature in the inner side is not monitored. The results show that wall made with wood wool and clay have higher thermal phase shift than wall made with mineral wool and gypsum. The highest impact is due to the use of a panel of clay instead of gypsum. The type of insulation has limited influence. The maximum difference between the two walls is 0.9 °C, which corresponds to an increase of performance of about ~5%. This value of ~5% is similar to the conclusion obtained by previous modellings performed by the BBRI and the EMPA. In order to prevent summer overheating, one should at first guarantee overnight ventilation and sunscreen during the daytime, and thereafter care about the type of insulating material.

Keywords: Biobased insulation · moisture buffering · thermal phase shift

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1 Introduction

The use of bio-based insulating materials is getting more and more attention from the construction field. In this way, official studies showed that it currently represents 8% of the insulation business turnover in France and is expected to grow at a rate of 10%/year until 2030. From initially small and medium size enterprises, the market is now being invested by large companies who also produces conventional materials [1, 2].

The development of these materials in modern buildings was initially driven by their ecological assets. However the recent commercial spread is mostly due to several studies performed by academics, manufacturers and laboratories delivering certifications who showed that bio-based insulating material performances can compete to conventional materials such as mineral wools or synthetic panels [3–7].

It is usually claimed that bio-based insulating materials are famous for their ability to maintain a comfortable indoor relative humidity (RH between 30 and 60%), thanks to their moisture buffering capacity; and to maintain an good temperature, thanks to their high thermal phase shifts.

The high hygroscopic properties of bio-based materials is known for decades. Sorption-desorption tests and moisture buffering value (MBV) tests have shown at lab scale that, taken individually, the bio-based insulating materials can indeed efficiently absorb and release the water vapour from the air [3, 5, 8, 9]. This has also been proved for hempcrete used as blocks or renders for inside insulation [10–12]. However, few experimental studies investigated the behaviour of flexible bio-based materials once integrated in a whole structure.

Among them, the study of Mortensen et al. [13] investigated the moisture buffering ability of cellulose compared to mineral wool in a large climatic chamber. When set behind a plaster board, the cellulose was able to effectively regulate the indoor relative humidity. According to the author the moisture buffer capacity of hygroscopic materials can be used to moderate peaks in the relative humidity (RH) of indoor air as well as moisture content variations in building materials and furnishing which can help to ensure healthier indoor environments by preventing many processes that are harmful such as growth of house dust mites, surface condensation and mould growth. However, the author also showed that the presence of non-permeable to water vapor paint on the gypsum board reduces this effect and concluded that more study had to be performed to assess the real influence on the indoor humidity depending on the construction layers.

One other significant study on the subject of hygroscopic regulation is the study made by Palumbo et al. [14]. The authors studied the performances of calcium alginate, wood fibres and EPS insulating materials at lab scale and then compared the results with a study performed at large scale on an ETICS wall. It was concluded that though the hygrothermal properties were significant at lab scale, no clear difference was visible at large scale.

Even fewer studies are available concerning the influence of flexible bio-based insulation materials on the indoor thermal inertia during hot summer conditions. With their high density and high thermal capacity values, the bio-based flexible insulation materials theoretically have better thermal phase shift and thermal effusivity values than mineral wools and especially compared to synthetic insulation. In this way for 200 mm thickness the thermal phase shift value of cellulose is theoretically 7–8 h whereas it only reaches

2–3 h for EPS and 3–4 h for mineral wools [9]. However, more and more questions are being raised about the real impact once they are set in the field mostly for two reasons: 1) several modellings performed by either the Belgian Building Research Institute (now named Buildwise) [15, 16] or the Swiss Federal Laboratories for Materials Science and Technology (EMPA) [17] have shown that the type of insulating material set in a roof with windows have a very limited effect. The type of insulating material (either rigid PIR, loose cellulose, flexible wood wool or flexible mineral wool) has only a very limited impact in the overheating in summer in rooms located behind pitched roof with skylight windows (5 to 10% of the impact). The most impacting factors were the overnight ventilation and the presence of sunscreen on the windows during the daytime (up to 66% of the impact); 2) It is generally accepted that the Cp values of bio-based materials are around 1800–2100 J/K.kg, whereas those of mineral wools are ~800–1000 J/K.kg, those of PUR/PIR are ~1400 J/K.kg and those of XPS are ~1300 J/K.kg. However, despite a large screening performed in 2022 on the technical data sheet of commercially available materials (hemp, grass, flax…), only one manufacturer provided an officially certified value of Cp for only one of his product (wood wool). More important, this value was lower than expected: a Cp of only 1220 J/K.kg. Discussions are ongoing between stakeholders about the necessity to adopt a new standard for the measurement of the Cp of bio-based materials. Due to their high hygroscopicity and heterogeneity, the interpretation of the results can greatly vary depending on the laboratory. However, since almost no certified Cp value are available, doubts about the high impact on thermal inertia of flexible bio-based materials seem to be justified. It is to notice that no doubts are emitted for the thermal inertia potential of rigid bio-based materials, such as rigid wood fiber board used for sarking applications, which have much higher densities.

In order to get a better understanding of the real impact of the bio-based materials, experiments were performed at large scale with a climatic chamber. In the first series of tests, the hygroscopic behaviours were investigated. In the second series of tests, the thermal inertias were investigated.

2 Methods

2.1 Materials

The materials used for the tests in the climatic chamber are listed in Table 1. Some of them where used for both moisture migration or thermal transition tests.

2.2 Characterization of Materials

Sorption-desorption tests were performed following the EN 12571 standard. These tests are essential to determine the hygroscopic behaviour of bio-based materials. Three samples of each material of 100 * 100 * 100 mm were dried until they reached a constant mass. Thereafter the humidity was set at either 20, 40, 60, 80 or 95%. At each step, the samples were weighted. When the mass was constant for each samples (no variation of more than 0,1% in 3 days), a different level of relative humidity was set.

Moisture buffer value tests were performed following the Rilem TC 275 HDB report. Three samples of each material of 150 * 150 * 150 mm were dried until they reached a

Table 1. Materials used in the study.

Material	Thickness (mm)	Density (ρ, kg/m^3)	Thermal conductivity (λ, W/mK)	Thermal capacity (Cp, J/kg.K)	Water vapour permeability	Individual thermal phase shift (φ, h)
Insulation						
Mineral wool	200	30	0,035	1030	$\mu = 1–2$	4,3 h (200 mm)
Flax	200	23	0,038	1550	$\mu = 1–2$	4,5 h (200 mm)
Wood wool	200	47	0,038	2100	$\mu = 1–2$	7,4 h (200 mm)
Membranes						
Closed membrane	0,31	–	–	–	$S_d = 2400$ m	–
Permeable membrane	0,32	–	–	–	$S_d = 5$ m	–
Panels						
OSB board	18	600–700	0,100–0,130	1350	$\mu = 114$*	1,1 h (18 mm)
Gypsum board	13	600	0,220	900	$\mu = 10$*	0,5 h (13 mm)
Clay board	22	1450	0,353	1100	$\mu = 16$*	1,1 h (22 mm)
External panel (wood fiber bitumen cladding)	18	250	0,048	2100	$\mu = 5$*	1,4 h (18 mm)

*: *values measured at Buildwise.*

constant mass. Once the dry point was reached, the specimen were stabilized at 23 °C/ 50%RH until they reached a constant mass. The specimen were sealed with aluminum tape on all faces, excepted the exchange surface. The target air velocity was 0.10 ± 0.05 m/s. It was measured with an anemometer in the three directions in representative conditions of the test (door close, specimen in place…). The samples were set in a basket to enable a correct air velocity. The samples were set in a circle with their exposed faces toward its centre. The test consisted in measuring the weight variation along daily cyclic variation of relative humidity (8 h at RH = 75%, then 16 h at RH = 33%). The weightings were performed manually 3 times a day. Analytical balance, capable of weighing the test specimens with an accuracy of 1% was used. The mass variation between the highest and the lowest value was calculated in absorption and in desorption for each cycle. The temperature and the relative humidity were recorded continuously with suitable sensors (each 5 five minutes) placed near the specimens. The average relative humidity was calculated for each cycle during absorption and desorption steps. The test ended when the stabilization criterion was met. The stabilization criterion required was a variation of mass variation lower than 5% between the last three cycles. The MBV of a specimen is the average value of the three stabilized cycles. The MBV of the material is the average value of the three specimen. The MBV is calculated as follows for each cycle and each specimen:

$$MBV = \frac{m_{high} - m_{low}}{\left(RH_{high,av} - RH_{low,av}\right)A} \tag{1}$$

$m_{high/low}$: higher/lower value of mass during the cycle (g),
$RH_{high,av/low,av}$: average value of relative humidity at high/low relative humidity level (% RH),
A: exchange surface area (m^2).

2.3 Measurements in Climatic Chambers

Relative humidity sensors were "Honeywell" brand and type "HIH-4021". These sensors provide values in volt that are thereafter converted to percentage of relative humidity.

The thermocouples were made of one wire of copper and one wire of aluminum. They provide a signal in volt. The wood humidity measurement were measured with two nails inserted in the wood rafter. An electrical current flow between these nails and the value of the electrical resistance (MΩ) can then be converted to wood humidity value (%) (Fig. 1).

Fig. 1. Left: relative humidity sensor and thermocouple/Right: wood humidity sensors.

The values measured by the sensors were sent to an Agilent monitoring apparatus, converted into physical units and then sent to Graphana software where the data could be read and collected (Fig. 2).

The aim of the tests was to simulate different outdoor and indoor conditions and to study the hygric and thermal behaviours of the two walls. In order to do so, two walls of 1,8 × 1,2 × 0,2 m were built between two climatic chambers.

Figure 3 shows the general scheme of the implementation. Figure 4 shows pictures of the walls at different building steps.

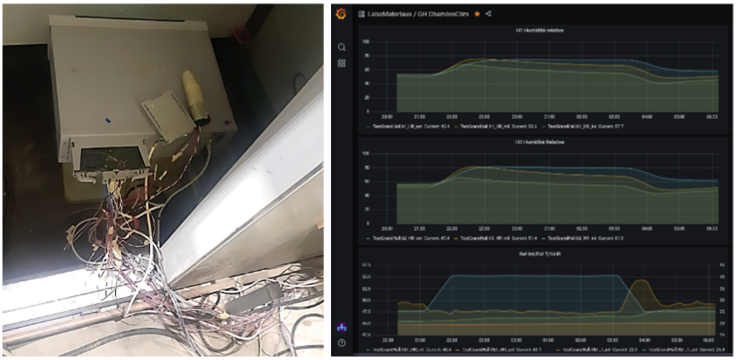

Fig. 2. Left: Agilent monitoring apparatus/Right: Graphana interface.

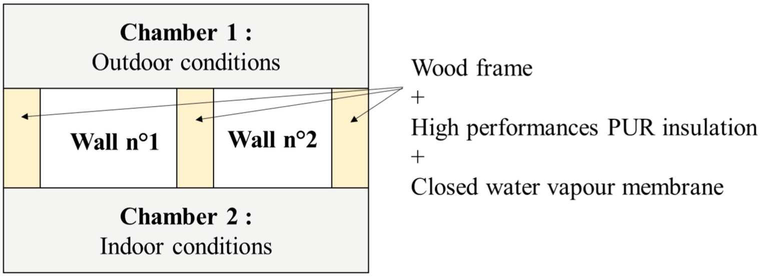

Fig. 3. Overview of the test implementation.

Fig. 4. Walls at different building steps.

For both panels, each type of sensors was set either in the indoor chamber, inside the panels or in the outdoor chamber. Additional temperature sensors were also set next to the render of each panel in the indoor side. Figure 5 shows some pictures of the implementation of the sensors.

The temperature and relative humidity were controlled by the internal apparatus of the climatic chambers. For the first series of tests, the moisture migration was studied. In

Fig. 5. Pictures of sensors.

order to do so, only a defined amount of water vapour was injected in the indoor climatic chamber. In order to do so, a HU-45 ultrasonic humidifier was used.

2.4 Tests Conditions

Two types of tests were performed: moisture migration or thermal transition tests. Two walls were set up for both tests. The indoor chamber had a volume of 21 m^3.

Moisture Migration Tests

The aim of the moisture migration tests were to study how the water vapour is absorbed, diffused and released by the bio-based insulating materials. These tests were performed to investigate the moisture buffering of the bio-based materials. For this test, flax was used as bio-based insulation. Indeed, this materials proved to be the most hygroscopic and the one with the highest sorption/desorption capacity. Mineral wool was used as comparison since it has no hygroscopicity.

Two types of tests were performed:

1) *"Temporary humidity"*: in that case the chamber n°1 was kept at 5 °C/RH = 80% during the whole procedure in order to simulate external cold weather. In the chamber n°2 the temperature was maintained at T = 23 °C in order to simulate indoor conditions. At first the chamber was conditioned for 48 h at RH = 40%. Then the conditioning was stopped and the relative humidity was sharply increased from 40% to 95% thanks to the injection of a define amount of water vapour (see Table 2) injected in 20 min with a humidifier apparatus. The aim of the test was to create a temporary high increase of the water vapour and to observe how this amount of water vapour migrated and was absorbed through the wall. These conditions could for example be closed to the ones encountered when having a shower in a bathroom or when cooking without ventilation;
2) *"Continuous humidity"*: in that case the chamber n°1 was kept at 5 °C/RH = 80% during the whole procedure. In the chamber n°2 the temperature was maintained at T = 23 °C. At first the chamber was conditioned for 48 h at RH = 40%. Then the

conditioning was set at RH = 95% for 60 h. These tests were performed to getter a better understanding of the dynamic of the water vapour migration through the walls.

Table 3 lists the different configurations of walls tested. It is to notice that for the *"Temporary humidity"* tests, the OSB boards were set in the indoor side directly next to the insulating material, whereas it is recommended for a proper implementation to always add a water vapour membrane between the OSB and the insulation. The aim of the water vapour membrane is to prevent a migration of a too high amount of water vapour throuh the insulating materials and thus prevent the possibility of condensation. However, in the present study, for the temporary tests, the water vapour membrane was not install in order to get a scientific understanding of the direct influence of the materials.

Table 2. Volume of liquid water for one injection during *"Temporary humidity"* tests.

Conditions	Vapour pressure (Pa)	Absolute humidity (g_{water}/kg_{dryair})	Absolute humidity (g_{water}/m^3))	g_{water} for a volume of 21 m^3
23 °C/40%	1123	7,0	8,4	176,3
23 °C/95%	2667	16,8	20,3	425,3
→ Volume of liquid water to be vaporized during 1 injection: 249 mL				

Table 3. Configurations of the walls for all humidity tests.

Test n°	Configurations of the walls (from indoor to outdoor)			
"Temporary humidity" tests				
1	/	OSB	Mineral wool	External panel
2	Gypsum board	OSB	Mineral wool	External panel
3	/	OSB	Flax	External panel
4	Clay	OSB	Flax	External panel
5	/	Permeable membrane	Flax	External panel
"Continuous humidity" tests				
6	OSB	Permeable membrane	Mineral wool	External panel
7	OSB	Permeable membrane	Flax	External panel

Thermal Transition Tests

The thermal transition tests were performed in order to assess the influence between either flexible bio-based insulating material vs. conventional mineral wool; and also between either clay board vs. conventional gypsum. For these tests, flexible wood wool was used since it is the material with the highest thermal phase shift (see Table 1). The *"Thermal Transition"* tests were performed as follow: Firstly the chambers were conditioned for 48 h. The chamber n°1 was conditioned at T = 16 °C/RH = 50% and the chamber n°2 was conditioned at T = 19 °C/RH = 50%. The test was thereafter launched and no further regulation of temperature and humidity was applied to the chamber n°2. The RH in chamber n°1 was maintained at 50% and the temperature underwent 4 stages of 6 h at T = 25 °C, 40 °C, 25 °C and finally 16 °C. The aim of this test was to simulate the indoor and outdoor conditions during a hot summer day. The Table 4 shows the different configurations of the walls for thermal transition tests.

Table 4. Configurations of the walls for thermal transition tests.

Test n°	Configurations of the walls (from indoor to outdoor)			
9	Clay board	OSB	Mineral wool	External panel
10	Gypsum board	OSB	Mineral wool	External panel
11	Clay board	OSB	Flax	External panel
12	Gypsum board	OSB	Flax	External panel

3 Results

3.1 Characterizations of Materials

Sorption-Desorption

Figure 6 shows the sorption-desorption curves for the materials studied during moisture migration tests. The mineral wool having absolutely no hygroscopic properties, its curves is not shown.

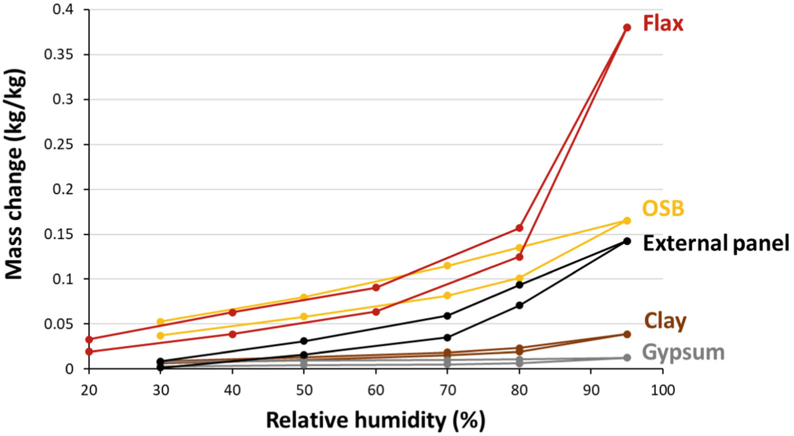

Fig. 6. Sorption-desorption curves.

It can be observed in Fig. 6 that flax is the material with the highest hygroscopicity, then comes OSB, external panel, clay and finally gypsum. Noticeably the OSB has similar properties as flax when the RH is below 80%. For this test, the total mass of flax in a wall is 13 kg, and the total mass of OSB is 25 kg. Below RH = 80%, the OSB is therefore expected to have a higher impact than flax on the regulation of the humidity inside the room.

Table 5 shows the moisture buffering values obtained for the different samples. For a better interpretation, Fig. 7 shows the MBV ranks. It can be observed that in line with sorption-desorption measurement, mineral wool has the lowest hygroscopicity. The gypsum board show a MBV value very close to what Rode et al. [18] listed in their review (between 0.55–0.65 g/(m^2.%RH)). The MBV value of gypsum can be classified as "moderate" according to the same authors. This is in line with the poor values obtained during sorption-desorption. Surprisingly the OSB board showed a "moderate" MBV value. The value can be considered as correct since it is very close to what was obtained in another study performed by Collet et al. [19] who obtained 0.53 g/(m^2.%RH). This confirms that for a neat understanding of the hygric properties of materials, both sorption-desorption and MBV measurement are needed. The external panel, which is made from wood fibers and bitumen, and which had relatively similar sorption-desorption curves as OSB, shows in contrary a "good" MBV value. This could be explained by the fact that OSB panel are much more dense compared to external panel (ρ_{OSB} = 600–700 kg/m^3 instead of $\rho_{\mathrm{External.panel}}$ = 250 kg/m^3). Flax insulation is another material that shows disparities between the static and dynamic measurements: despite it showed the highest sorption-desorption performances, its MBV value could only be considered as "moderate-good". In another way, whereas the clay showed relatively low sorption-desorption values, its MBV values were considered as "good".

Table 5. Moisture buffering values obtained from 3 samples.

Material	Mineral wool	Flax	OSB board	Gypsum board	Clay board	External panel
MBV average value (g/(m^2.%RH))	0.29	1.05	0.52	0.66	1.27	1.61
MBV standard deviation g/(m^2.%RH))	0.03	0.05	0.09	0.02	0.04	0.02

3.2 Moisture Migration Tests

Influence of the Insulating Material

Tests n°1 and n°3 enabled to compare the influence of the flexible insulating material. In test n°1 the insulating material was mineral wool and in test n°3 it was flax.

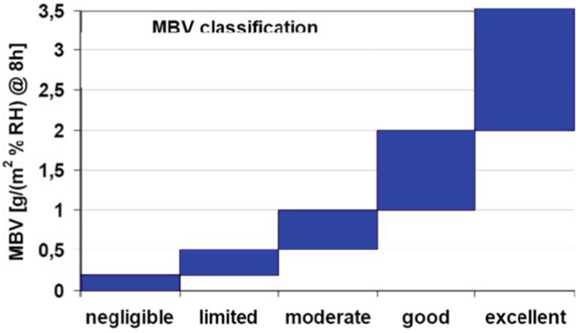

Fig. 7. Moisture buffering values classification according to Rode et al. [18].

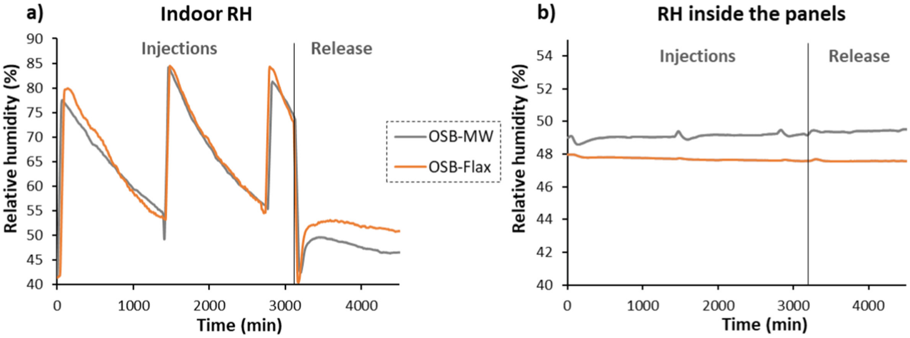

Fig. 8. Influence of insulating material: comparison of *"Temporary humidity"* tests n°1 and n°3. a) indoor relative humidity; b) relative humidity inside the insulation.

It can be observed in Fig. 8a that the behaviors during the injection of water vapour were very similar whatever the type of insulating material. Though the amount of water vaporised was set to reach a relative humidity of 95%, the indoor RH did not exceeded 85%. This could be explained by the fact that the relative humidity was very quickly absorbed by the OSB board in the range between RH = 80 and 100%. Indeed, the sensors were able to perform only one acquisition every 15 min. The relative humidity values then slowly decrease at the same rate for both tests: it decreases almost linearly from RH ~80% to ~55% in 24 h. The slow and almost identical decrease of RH for both tests could be explained by the fact that the OSB boards act as water vapour barriers (μ = 114/Sd = 2 m) and prevent the insulating material behind them to have a real impact on the moisture absorption. Furthermore, despite the OSB had high sorption-desorption performances (Fig. 6), its MBV value was considered as "moderate" (Table 5), which explain the very slow decrease.

Figure 8b shows tiny jolts in the relative humidity of the mineral wool wall at the times where the injection of moisture was high (t = 10, 1600 and 2900 min). In contrary, this was not observed for the flax wall. Despite this, the relative humidity remained globally very stable during all the test steps for walls with mineral wool or flax. It is supposed that the major amount of moisture was slowly absorbed by the OSB board and did not go through the insulation.

During the step of release, the RH values of the indoor chamber increased back for both tests. However, the release of humidity was more important and last longer for the wall with flax than for one with mineral wool. In this way, after 24 h of release, the relative humidity decreased to RH = 46,9% with mineral wool wall whereas it was still at RH = 50,9% with flax.

Influence of the Render

Tests n°1–2 and tests n°3–4 were compared to study the influence of the render.

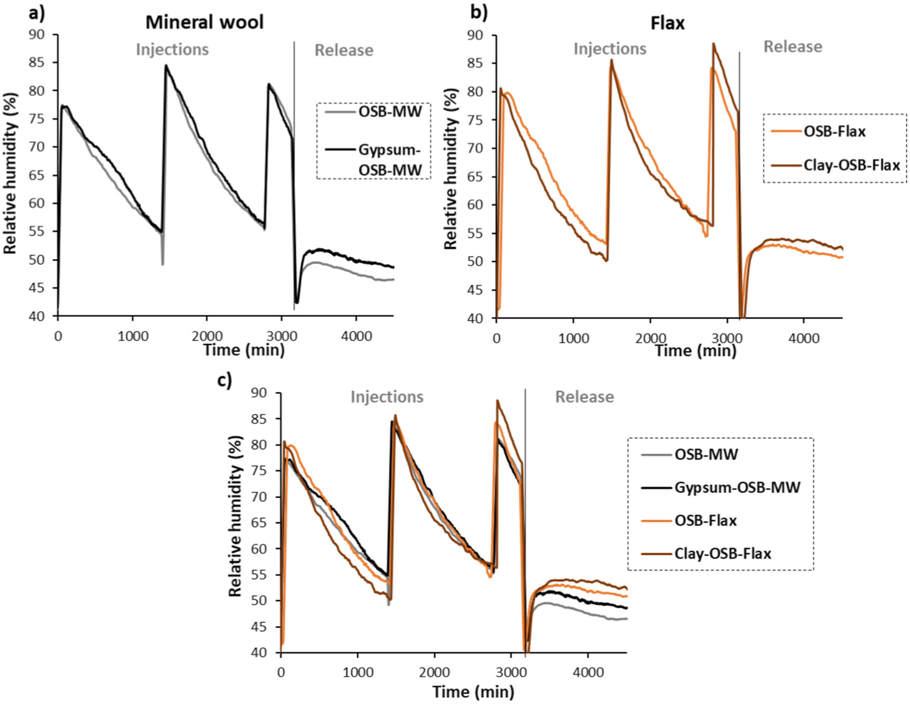

Fig. 9. Influence of render: comparison of *"Temporary humidity"* tests n°1–2 and n°3–4. a) influence of gypsum; b) influence of clay; c) comparison for all compositions.

It can be observed in Fig. 9 that the presence of gypsum and clay increases the amount of moisture released during the last steps of the tests. Interestingly the relative humidity in the room decreased more quickly in the presence of clay during the injection steps.

Influence of the Membrane

Figure 10 shows the moisture migration tests for walls with and without membranes. For a better understanding, comparisons were performed with the results obtained for the other panels.

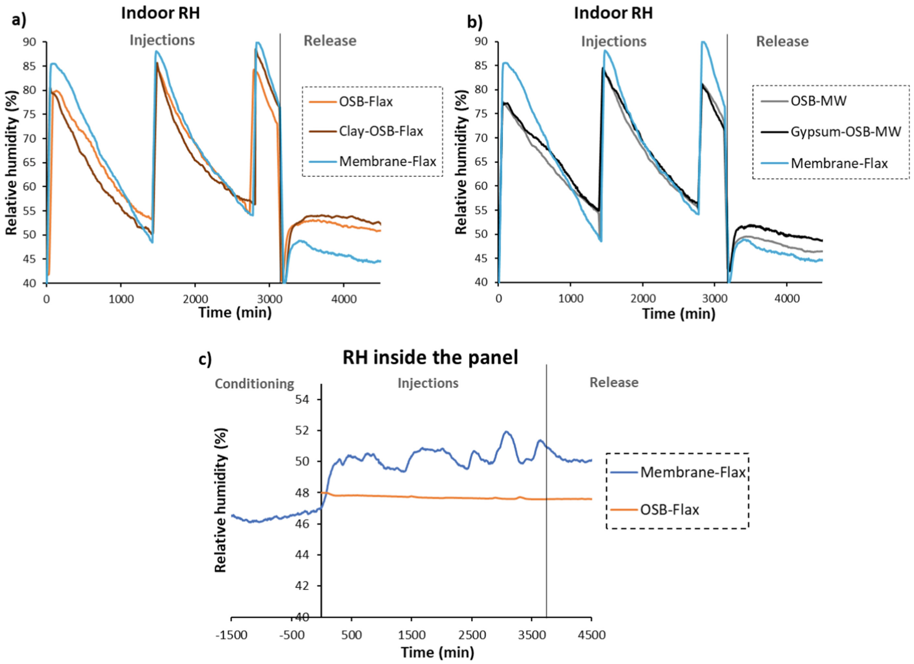

Fig. 10. Influence of membrane: comparison of "*Temporary humidity*" tests. a) comparison between panels using flax; b) comparison between panels using mineral wool; c) relative humidity inside the insulating panels using either a permeable membrane or a OSB.

It can be observed in Fig. 10a that the relative humidity values goes to higher values in the indoor chamber during the injection when a membrane is present. Indeed, in the other cases the moisture was directly in contact with the OSB board or the render (gypsum/clay) and was absorbed very quickly in ranges comprised between RH = 80 and 100%. With the presence of a membrane, the moisture had more difficulty to penetrate through the membrane which explains the longer time for the relative humidity to decrease.

It can be observed that with a membrane the release of humidity value during the step of release is very low. In fact, it is the lowest release of moisture observed for all tests (Fig. 10a & b). This is logical since the membrane prevent the moisture to go through the other side.

Figure 10c shows the relative humidity value inside the insulation. It can be observed that the relative humidity value increases when the membrane is present. This is not the case if the OSB board is present. This confirm the theory that the moisture is at first absorbed by the OSB board and then partially diffuse through the insulating material.

Noticeably, the relative humidity value remained stable inside the insulation during the step of release. It is supposed that in that step, the release of relative humidity only comes from the superficial layer of the insulating material.

In conclusion, in case of temporary rise of humidity inside a room, the regulation of the indoor humidity is therefore impacted by order of influence by:

OSB board >> clay render > gypsum render > bio-based insulating material.

Continuous Injection of Water Vapour

The tests n°6 and 7 were performed to observe the evolution of the relative humidity values inside the insulation when the indoor relative humidity is very high and the panel has an OSB board and a permeable membrane (Sd = 5 m).

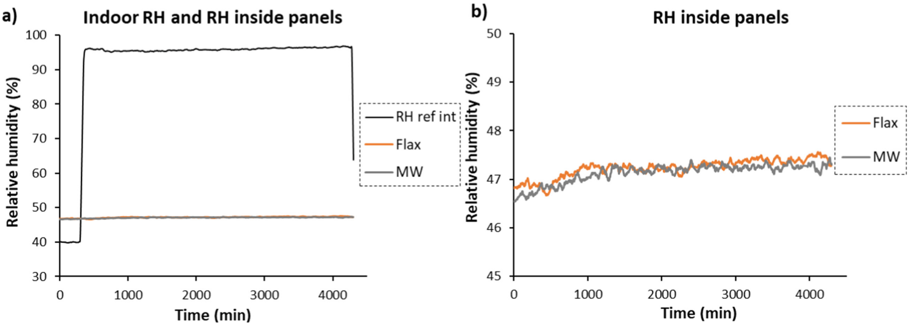

Fig. 11. *"Continuous humidity"* tests. a) Overview; b) Zoom on relative humidity values inside the insulation.

It can be observed in Fig. 11b that the relative humidity inside the insulation of walls using both flax and mineral wool evolved very lightly (+2% after 60 h). Despite the fact that the OSB and the membrane were permeable to water vapour ($Sd_{OSB} = 2$ m and $Sd_{Membrane} = 5$ m), the migration of relative humidity from the indoor chamber at RH = 95% through the wall was therefore very limited. These result are in accordance with the sorption-desorption curves (Fig. 6) and with the *"Temporary humidity"* test showed in Fig. 10. The OSB boards act as both water vapour barriers and moisture absorbent and prevent its diffusion through the walls. Furthermore, the MBV value of OSB being "moderate" and its sorption-desorption ability being high, the OSB board can intake water vapour humidity for a long time without letting it pass.

It is expected that eventually with relative humidity kept at 95%, the moisture would penetrate through the walls and increase the relative humidity inside the insulating material. However, the relative humidity would have to remain high for more than 60 h, which would be far from domestic and realistic use. Behind both an OSB board and a permeable membrane (Sd = 5 m), the insulating material seems therefore almost not impacted by the quick and short indoor relative humidity variations.

3.3 Thermal Transitions Tests

Tests Summary

Figure 12 shows an overview of the temperatures that have been observed for the outdoor conditions and for the indoor conditions during the thermal transition tests. It is to remind that before the tests, the outdoor chamber was conditioned 24 h at 16 °C/RH = 50%, and the indoor chamber was conditioned at 24 h at 19 °C/RH = 50%.

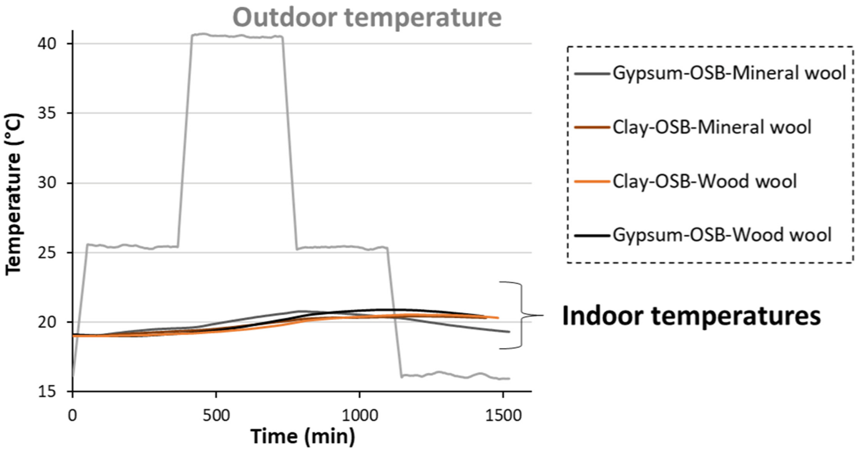

Fig. 12. Overview of the "*Thermal transition*" tests.

Figure 13 shows the graphs of the temperatures obtained at the indoor surface of the renders for the different wall compositions. Figure 14a shows the maximal temperatures. Figure 14b shows the time needed for the different walls to reach T = 20,81 °C, which is the maximum temperature that has been reached by the wall with clay and wood wool. The time shift values are defined by the additional time needed by the walls to reach T = 20,81 °C compared to the wall with gypsum and mineral wool.

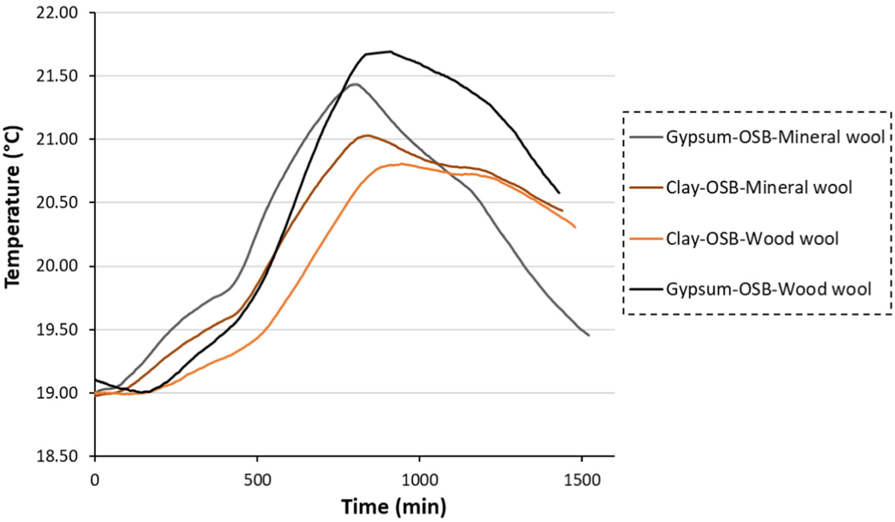

Fig. 13. Temperature on the indoor side of renders for all compositions.

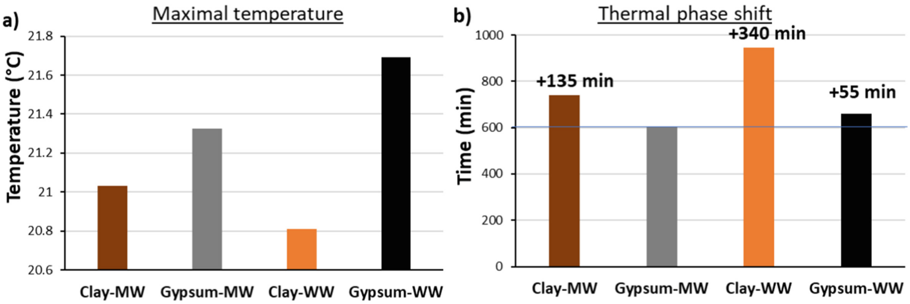

Fig. 14. Results for the temperature on the renders. a) maximal temperature; b) time needed to reach T = 20,81 °C compared to gypsum-MW wall.

Several observations can be made:

- The wall with gypsum+mineral wool showed the lowest thermal phase shift. This result is logical since both gypsum and mineral wool have low φ values (see Table 1).
- The maximal temperature is reached for the wall with gypsum+wood wool (T = 21,69 °C). This can be explained by the combination of two facts: 1) the wood wool have a higher lambda value than the mineral wool ($\lambda_{\text{Wood wool}}$ = 0,038 W/m.K, whereas $\lambda_{\text{Mineral Wool}}$ = 0,035 W/m.K); 2) the gypsum has the lowest thermal phase shift (φ_{Gypsum} = 0,5 h, whereas φ_{Clay} = 1,1 h). Furthermore, these are the commercial lambda values that have been determined at RH = 0%. It is suspected that in the present case at RH ~ 50% and higher temperatures, the $\lambda_{\text{Wood Fiber}}$ might be even higher [3, 9].
- The comparisons between walls with clay+mineral wool and gypsum+mineral wool, and also between clay+wood wool and gypsum+wood wool in Fig. 14 highlight that the decrease of the maximal temperature value and the longer thermal phase shift are mostly brought by the presence of a clay board. This is strengthened by the graphs trends presented in Fig. 13.
- Results show that the wall with clay+wood wool is the one with the lowest maximal temperature and the highest thermal phase shift. In that case, there is a synergy of the high thermal phase shifts of both clay and wood wool which enables to bring a better thermal inertia of the wall during the cycle. This better thermal inertia compensate the higher thermal conductivity of the wood wool.
- The difference between the outdoor temperature and the wall clay+wood wool is the highest: ΔT = 40–20,8 = 19,2 °C. The difference between the outdoor temperature and the wall gypsum+wood wool is: ΔT = 40–21,7 = 18,3 °C. The difference between these two walls is 0,9 °C, which corresponds to an increase of performance of 4,6%. This value is similar to the conclusion obtained by the modellings performed by Buildwise (ex-BBRI) and the EMPA that compared different types of material (mineral wool, cellulose, wood fibres) for roof insulation [15–17]. In these studies the authors concluded that effective cooling was mostly impacted by the combination of overnight ventilation and the presence of sunscreen on the windows during the daytime rather than by the type of insulating material. The modelling showed that

the impact on the summer comfort of the type of insulating material was comprised between 5 and 10%, which is close to the 4,6% obtained in this study.
- It can be observed in Fig. 13 that during the last step, the temperatures decrease much quicker for the walls with gypsum than for the wall with clay. It could be judicious in a future work to perform similar tests with several continuous cycles. This would enable to see if the indoor temperature stabilizes itself at an acceptable value or continue to increase cycle after cycle.

4 Conclusions

This study enabled to collect interesting information about the hygroscopic and thermal behaviours of bio-based materials implemented in a wood frame wall.

It was observed that the moisture-buffering effect of a wall without permeable membrane was impacted by order of influence mostly by the OSB board, then by the clay render (or with lower impact by the gypsum render), and finally by the bio-based insulating material. However, despite its high sorption-desorption capacity, the OSB showed a low MBV value. OSB could therefore be interesting for a long-term regulation of the hygric properties of a building, but seems not very interesting for deep and intense day-to-day regulation.

It was shown that behind an OSB board and a permeable membrane (Sd = 5 m), the hygroscopic impact of the insulating material on quick and short indoor relative humidity variations was almost insignificant.

Experiments revealed that the presence of thick clay board (22 mm) instead of conventional gypsum board (13 mm) is the factor that has the highest impact on the thermal inertia of the wall. It also showed that, in order to optimize the configuration and manage to obtain the lowest temperature and the longer thermal phase shift, wood wool should be associated with clay board rather than gypsum board.

In correlation with previous modellings, the experiments showed that the impact of flexible bio-based insulating materials on the thermal phase shift was relatively low (~ 5%) compared to flexible mineral wool. If one want to improve summer comfort, one should at first act on the sunscreen and nightcooling, and only after on the type of flexible insulation.

If, in spite of everything, the optimization of the thermal inertia remains an objective, one will then turn to bio-based insulating materials with densities higher than 100 kg/m^3 (type of rigid wood fibers, hemp-lime, hempcrete) or one will adapt the type/thickness of the interior finishing (plaster, clay…).

References

1. CODEM-BATLAB. Guide de la rénovation de parois à l’aide de matériaux biosourcés (2021)
2. ADEME; DGE. Recensement des produits biosourcés disponibles sur le marché et identification des marchés publics cibles (2015)
3. Ormondroyd, G.A.: An industry prioritised survey of thermal, mechanical, hydro and decay properties of natural fibre insulation materials (2017)

4. Koh, C.H., Gauvin, F., Schollbach, K., Brouwers, H.J.H.: Investigation of material characteristics and hygrothermal performances of different bio-based insulation composites. Constr. Build. Mater. **346**, 128440 (2022). https://doi.org/10.1016/j.conbuildmat.2022.128440
5. Lafond, C., Blanchet, P.: Technical performance overview of bio-based insulation materials compared to expanded polystyrene. Buildings **10** (2020). https://doi.org/10.3390/BUILDINGS10050081
6. Fachagentur Nachwachsende Rohstoffe. Nachwachsende Rohstoffe. Zeitbild (2016)
7. HWK. Untersuchung des Langzeitverhaltens von Dämmstoffen aus nachwachsenden Rohstoffen in Bauteilen (2016)
8. Vėjelis, S., Gnipas, I., Keršulis, V.: Performance of loose-fill cellulose insulation. Mater. Sci. **12**, 338–340 (2006)
9. Jones, D., Brischke, C.: Performance of nio-based building materials (2017)
10. Gourlay, E., Borderon, J.: Modélisation des besoins de chauffage et de refroidissement d'un bâtiment en béton de chanvre (2021)
11. Collet, F., Pretot, S.: Experimental investigation of moisture buffering capacity of sprayed hemp concrete. Constr. Build. Mater. **36**, 58–65 (2012). https://doi.org/10.1016/j.conbuildmat.2012.04.139
12. Asli, M., Brachelet, F., Sassine, E., Antczak, E.: Thermal and hygroscopic study of hemp concrete in real ambient conditions. J. Build. Eng. **44** (2021). https://doi.org/10.1016/j.jobe.2021.102612
13. Mortensen, L.H., Peuhkuri, R., Rode, C.: Full scale tests of moisture buffer capacity of wall materials. In: 7th Nordic Symposium on Building Physics, pp. 662–669 (2005)
14. Palumbo, M., Lacasta, A.M., Giraldo, M.P., et al.: Bio-based insulation materials and their hygrothermal performance in a building envelope system (ETICS). Energy Build. **174**, 147–155 (2018). https://doi.org/10.1016/j.enbuild.2018.06.042
15. Flamant, G., Heijmans, N.: Capacité thermique des isolants et risque de surchauffe (2010)
16. Bock, D., Heijmans, N.: Surchauffe estivale: impact mineur de la nature de l'isolant des toitures à versants (2021)
17. EMPA. Protection thermique estivale des pièces sous les combles Analyse des facteurs d'influence sur le climat intérieur (2008)
18. Rode, C., Peuhkuri, R., Time, B., et al.: Moisture buffer value of building materials. J. ASTM Int. **4**, 100369 (2007). https://doi.org/10.1520/jai100369
19. Collet, F., Prétot, S., Colson, V., et al.: Hygric properties of materials used for isobio wall solution for new buildings. Acad. J. Civ. Eng. **37**, 349–355 (2019)