3rd International Conference on Bio-Based Building Materials

June 26th - 28th 2019
Belfast, UK

HYGRIC PROPERTIES OF MATERIALS USED FOR ISOBIO WALL SOLUTION FOR NEW BUILDINGS

F. Collet[1*], S. Prétot[1], V. Colson[1,2], C.R. Gamble[3], N. Reuge[1], C. Lanos1
[1] Université de Rennes, Laboratoire de Génie Civil et Génie Mécanique, Rennes, France
[2] Cavac Biomatériaux, France
[3] Stramit International Ltd
*Corresponding author; e-mail: florence.collet@univ-rennes1.fr

Abstract

The European ISOBIO project allowed to both develop new bio-based building insulation materials and improve industrial products from the partners of the project. It leaded to several multi-layers solutions to be used as typical wall for new building or for retrofitting. The hygrothermal behavior of these walls is studied experimentally (two demonstrator buildings and one laboratory test-wall) and numerically.
This study investigates the hygric characterization of the materials used to produce the core of the new wall solution: compressed straw board (CSB), commercial oriented strand boards (OSB), soft insulation panels (Biofib trio, CAVAC), rigid insulation panels developed within ISOBIO project (CAVAC panel). This paper presents the methods and the results obtained on absolute and apparent densities, total porosity, sorption isotherm, water vapor permeability at dry point and at wet point, and moisture buffer value. The studied materials are highly to very highly porous (60 to 98 %). They are hygroscopic. Their water vapor resistance factor is low for Biofib insulation, high for OSB and medium for CSB and CAVAC panels. It decreases between dry point and wet point in link with the hygroscopicity of materials. Their MBV gives them moderate to good moisture buffering ability (respectively for CSB and OSB, and for Biofib and CAVAC panel). The study provides an entire set of results that widely characterize the hygric behavior of studied materials and allow to compare them. It underlines very different behaviors, particularly under transient conditions. These data are useful to be implemented in numerical models that simulate hygrothermal behavior at wall scale.

Keywords:
Bio-based building materials, sorption isotherm, water vapor permeability, Moisture Buffer Value

1 INTRODUCTION

The European ISOBIO project aims to both develop new bio-based building insulation materials and improve industrial products from the partners of the project. This project started in 2012. In a first time, agro-resources used as raw materials were characterized on chemical and multi-physical point of view [Viel 2018]. Then, bio-based composites to be used as rigid insulation panels were developed [Viel 2017] [Colson 2017]. Finally, several multi-layers solutions were defined to be used as typical wall for new building or for retrofitting. The hygrothermal behavior of these walls is studied experimentally (two demonstrator buildings and one laboratory test-wall) and numerically. The new building typical solution wall is made of a wood frame and a clay-based plaster (Claytec plaster), a compressed straw board (CSB), a commercial vapor check and airtightness membrane, a commercial oriented strand board (OSB), soft insulation panels (Biofib trio, CAVAC), rigid insulation panel (CAVAC panel) and an hemp-lime render (BCB render).

This study investigates the hygric characterization of the materials used to produce the core of this solution (CSB, OSB, Biofib trio and CAVAC panel) in order to qualify their hygric behavior, compare them and highlight their role in a multi layers wall. It also provides input data In order to accurately predict the hygrothermal behavior of the wall. This paper presents the materials, the experimental methods and the results obtained on apparent and absolute densities, total porosities, sorption isotherms, water vapor permeabilities at dry and wet points and moisture buffer value.

2 MATERIALS

Four materials, constitutive of the ISOBIO typical wall for new buildings, are investigated in this study (Fig. 62).

The Compressed Straw Board (CSB) is provided by STRAMIT, one of the industrial partners of the ISOBIO project. The boards are produced with a patented process where the straw bales are wet and compressed at high temperature, ensuring gluing of straw [Glassco 1987]. The compressed straw is embedded between cardboards. The CSB panel is 40 mm thick. According to the technical notice, the density is about 380 kg/m^3 and the water vapor resistance factor is 9.7.

The OSB is the commercial product AGEPAN® OSB 3 PUR. It is used for structural purpose and airtightness. The OSB panel is 12 mm thick. According to the technical notice, the density is higher than 600 kg/m^3 and the water vapor resistance factor is 150 at wet state and 200 at dry state.

The Biofib trio is an insulating wool made of 92 % of natural fibers (flax, hemp and cotton fibers), and 8 % of PE. Two thicknesses are available: 145 mm and 45 mm. According to the technical notice, the density is about 30 kg/m^3 and the water vapor resistance factor is lower than 2.

The CAVAC panel is developed during the ISOBIO project. It is a 45 mm thick rigid insulation panel made of hemp shiv and environmentally friendly binder. Up to now, no data are available for this new product.

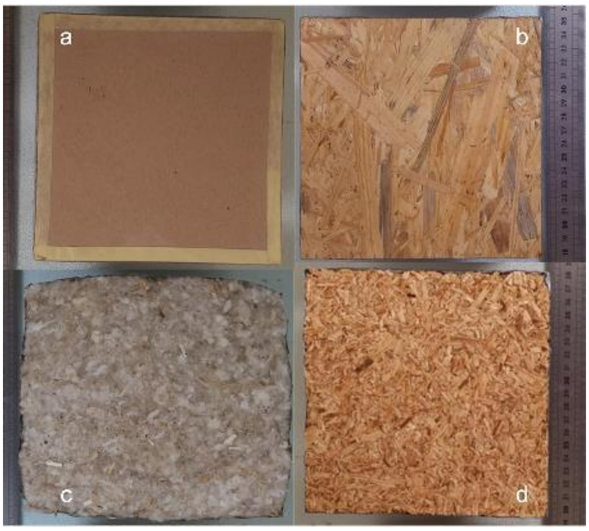

Fig. 62 : Studied materials: a) CSB, b) OSB,

c) Biofib, d) CAVAC.

3 EXPERIMENTAL METHODS

3.1 Specimens

Two sizes of specimens are considered. The specimens are cut in panels, their thickness is the same as the panel's one.

For sorption isotherm, the specimen are about 50 mm × 50 mm × thickness for Biofib and CAVAC panels. They are about 150 mm × 150 mm × thickness for CSB and OSB.

For water vapor permeability and MBV, all the specimens have an exchange surface area about 150×150 mm², with the thickness of the panel. The exchange areas are measured by image analysis.

3.2 Physical properties

The apparent density is calculated from the size and mass measurements for all specimens. The size is measured with an electronic caliper and the weigh with a scale. The accuracy of the scale depends on the specimen weight w (0.04 g for w>300 g and 0.0004 g for w < 300 g). The apparent density is measured after stabilization at (23°C, 50%RH) and at dry state.

The absolute density is measured by pycnometry method, using acetone as non-reactive liquid. The samples are prepared following two protocols:

- materials are manually crushed (or cut for OSB)
- materials are milled with a Ultra Centrifugal Mill ZM 200 from Retsch, a high speed rotor mill, except for OSB for which it was not possible.

The total porosity is calculated from apparent and absolute densities.

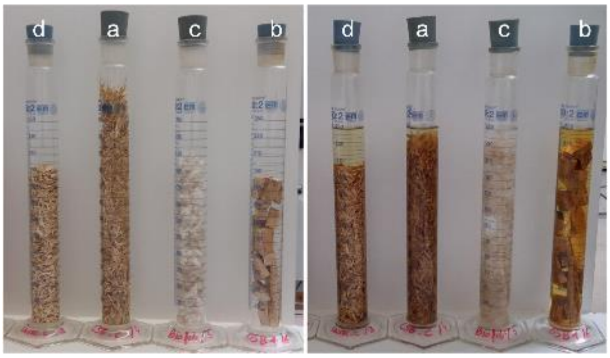

Fig. 63: Pycnometry - protocol 1: crushed / cut specimens a) CSB, b) OSB, c) Biofib, d) CAVAC ; left : without acetone, right : with acetone.

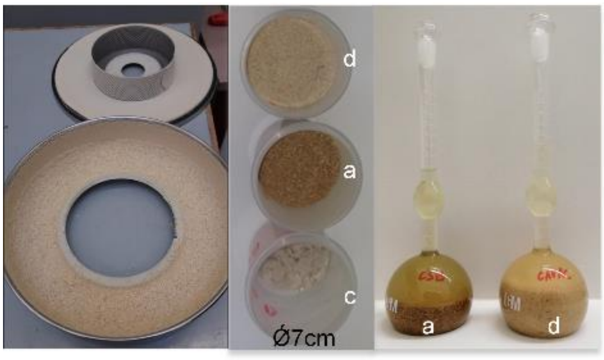

Fig. 64 : Pycnometry - protocol 2 - left: miller, middle: milled samples, right: Le Chatellier pycnometers - a) CSB, c) Biofib, d) CAVAC;

3.3 Sorption isotherm

The sorption isotherms are measured at 23°C following a discontinuous method. Firstly, specimens are dried at 60°C in an oven and stabilized at dry state with silica gel at 23°C. Then, specimens are stabilized at successive relative humidity in a climate chamber (Votsch 0034): 30, 50, 65, 83 and 95 %RH. The weighing is performed out of the climate chamber with the same analytical balances as for physical properties. More, for one specimen (CAVAC), the mass is recorded continuously. According to EN ISO 12571 standard [EN ISO 12571, 2000], the stability is reached when the difference is lower than 0.1% for three consecutive weighing with 24 hours' time step.

3.4 Water vapor permeability

The water vapor permeability is obtained with the cup method at 23°C for dry point (0/50) and wet point (53/88). The measurement is based on the ISO 12572 standard [ISO 12572, 2016]. Previously to the test, the specimens are stabilized at 23°C, 50 %RH. Then, the specimens are sealed on a cup where silica gel or salt solution ensures the relative humidity in the cup (Fig. 65). The cup is placed in a climate chamber which ensures the relative humidity out of the cup and provides air velocity higher than 2 m/s in order to make the air layer resistance negligible. The cup is weighed each day from monday to friday out of the climate chamber with the same analytical balance as for previous tests. Ambient conditions are monitored with Sensirion SHT 75 sensors calibrated with salt solutions (Fig. 66). Water vapor pressure is calculated from temperature and relative humidity.

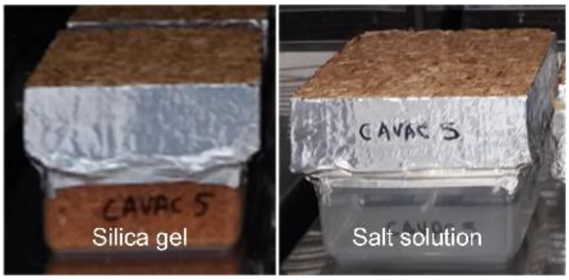

Fig. 65: Water vapor permeability, dry and wet cups.

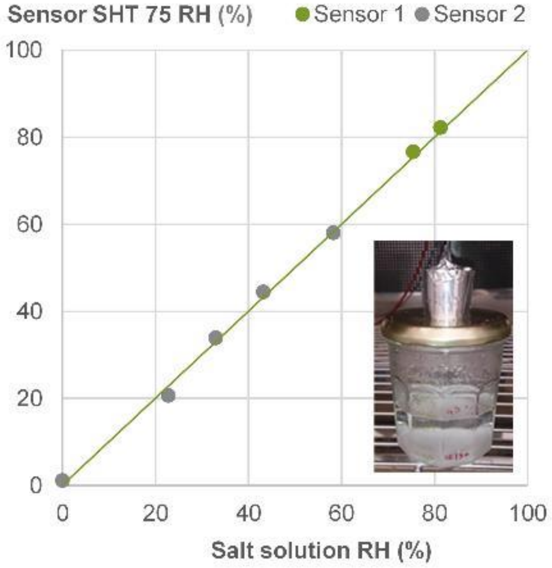

Fig. 66: Calibration of Sensirion SHT 75 sensors.

The slope of mass versus time is calculated on five consecutive values. The steady state is reached when the slope is constant within ± 5 % of the mean value for five successive determinations. The vapor transmission rate with masked edge (g_{me}) is calculated from the slope and from the exchange area (average of the upper and lower areas). As the edge of specimens overlaps the edge of the cup, the correction factor (g_{me}/g) is calculated from the width of the masked edge, the thickness of specimen and the hydraulic diameter. The vapor transmission rate ignoring the masked edge (g) is then deduced.

The water vapor permeability is obtained from the flux and the difference in water vapor pressure. As required in the standard, the resistance of the air gap between the base of the specimen and the silica gel or the salt solution is taken into account in the calculation. The water vapor resistance factor is the ratio between the water vapor permeability of air and the water vapor permeability of the studied material.

3.5 Moisture Buffer Value

The moisture buffer value is measured following the Nordtest project's protocol. It relates the amount of moisture uptake/release to the exchange area and to the relative humidity step during daily cyclic variations (8 hours at 75%RH, and 16 hours at 33%RH)(Eq. 1).

$$MBV = \frac{\Delta m}{A.(RH_{high} - RH_{low})} \qquad (1)$$

MBV: moisture buffer value, g/(m².%RH),

Δm: moisture uptake/release during the period, g,

A: open surface area, m^2,

$RH_{high/low}$: high/low relative humidity, %RH.

Previously to the test, specimens are sealed on all but one surface and are stabilized at 23°C, 50%RH. The test is performed in a climatic chamber (Vötsch VC4060) where ambient temperature and relative humidity are monitored continuously with the sensor of the climatic chamber and are recorded each 5 minutes with a SHT75 sensor, which was calibrated with salt solution. The air velocity in the surrounding of the specimen meets the requirement of the Nordtest protocol [Rode 2005], being low enough to be representative of air velocity met in indoor environments.

Fig. 67: Experimental bench for MBV measurment.

4 RESULTS

4.1 Physical properties

There is a wide range of bulk density for studied materials, from 28 kg/m^3 for Biofib to 570 kg/m^3 for OSB (Tab. 23).

For OSB and Biofib, the values found are close to the ones given by producer (discrepancy about 5 %). For CSB, the measured bulk density is 30 % higher than the one given by the producer.

The absolute densities are close to values found on bio-aggregate when the specimens are not milled [Viel 2018]. It is about 1400 to 1600 kg/m^3. The absolute densities found with protocol 1 are lower than the ones found with protocol 2. This is probably due to the fact that all porosity is not accessed when the specimen is not milled. For CSB, the discrepancy is low (1.2 %) while for CAVAC, it is higher (11.6 %).

There is a wide range of porosity. OSB shows the lowest porosity. The accessible porosity when it is cut is 60.9 %. As expected, the insulation wool Biofib shows the highest porosity, about 98 %. CSB and CAVAC panels show middle porosities, respectively 72 and 88 %.

Tab. 23 : Physical properties of studied materials – apparent and absolute densities (kg/m^3), porosity (%)

	CSB	OSB	Biofib	CAVAC
$\rho_{app,\ 23°C,\ 50\%}$	501	570	28.4	200
$\rho_{app,\ 23°C,\ dry}$	449	551	26.5	190
Manually crushed sample, $V_{pycnometer}$ = 250 ml				
$\rho_{s,1}$	1588	1412	1439	1427
n_1	71.7	60.9	98.0	86.7
Milled sample, Le Chatellier pycnometer				
$\rho_{s,2}$	1608	-	1609	1615
n_2	72.0	-	98.2	88.2

4.2 Sorption isotherm

The sorption kinetics are given Fig. 68 for all materials, for 0-30 %RH to 65-80 %RH steps. The kinetics observed are very different between the studied materials. Biofib and CAVAC exhibit the fastest increase in water content while CSB and OSB water content evolves more slowly. For each step, the two third of total increase in water content are reached after one days of exposure for Biofib and CAVAC. For OSB, this time ranges from seven to ten days, depending on the RH step. The longest time is observed for CSB and ranges from seven to fourteen days. After ten days of exposure at 80%RH, CSB specimens swelled. Finally, the kinetics are fastest for the materials with the highest porosity. When the porosity decreases, the tortuosity also impacts the water vapor penetration in the materials. More, it should be underlined that in the case of CSB, the card board may delay the water uptake.

The sorption isotherms are given Fig. 69 for all materials. The curves are sigmoid that can be classified as type II or III according the IUPAC classification [IUPAC 1986]. This is consistent with the fact that these classes are given for macroscopic media.

For 30 %RH, all the materials show similar water content, about 3%. Then, Biofib shows the lowest water content due to its fibrous structure. Up to 65 %RH, CSB, OSB and CAVAC water contents are close. At higher relative humidity, the water content of CAVAC get highest.

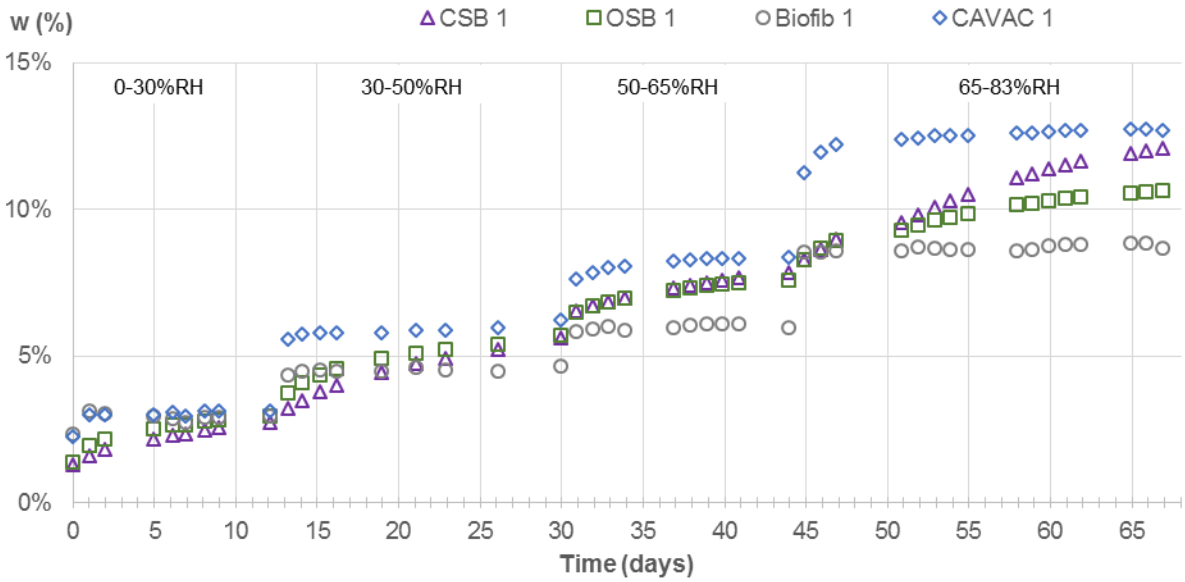

Fig. 68: Sorption kinetics

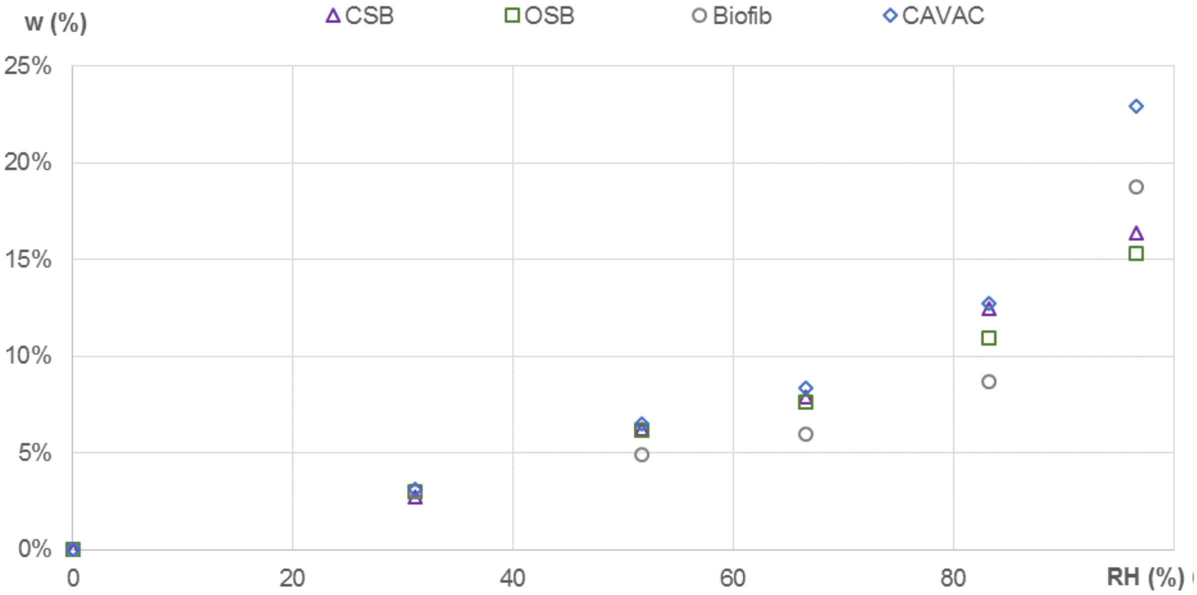

Fig. 69: Sorption isotherms

4.3 Water vapor permeability

The kinetics of mass related to the exchange surface area and corrected regarding the masked edge effect are given Fig. 70 for the dry point and Fig. 71 for the wet point. For the dry point, the kinetics obtained for CSB and OSB are close. They are slightly higher for CAVAC and much higher for Biofib. The kinetics obtained at wet point are higher than the ones obtained at dry point. The values obtained on OSB remain the lowest ones and the ones obtained on Biofib the highest.

The points taken into account to calculate the slope (and thus the water vapor permeability and the water vapor resistance factor) are identified by dash lines on the figures. The water vapor resistance factors are given Tab. 24 and Fig. 72 versus density. The water vapor resistance factors range from 3.6 to 138.3 at dry point and from 2 to 45.4 at wet point. At dry point, the water vapor resistance increases significantly with density, due to decrease in porosity. Form dry point to wet point, the water vapor resistance factor is divided by 1.8 to 3.2, this is due to the hygroscopicity of materials.

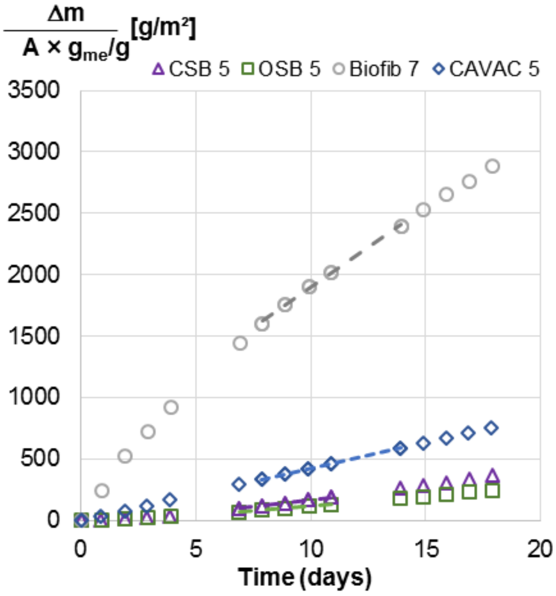

Fig. 70: Measurement of water vapor permeability at dry point (0 – 50 %RH)

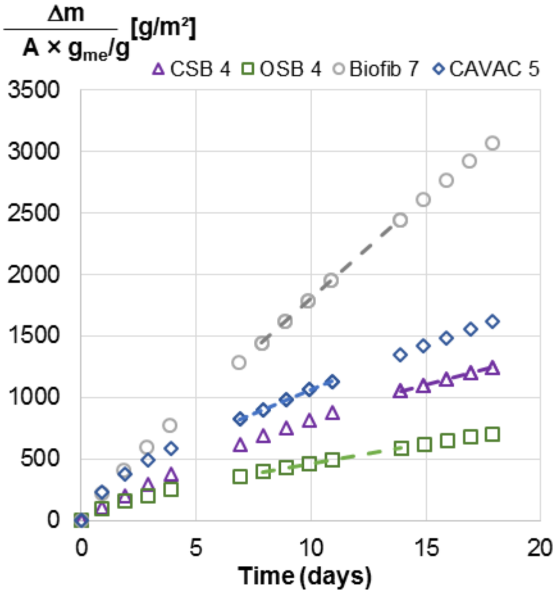

Fig. 71 : Measurement of water vapor permeability at wet point (53- 88 %RH)

As expected, the Biofib shows the lowest water vapor resistance factor. Actually it is a material with very high (98 %) and connected porosity (fibrous material). The values are in the range of the values given by the producer and are close to the one given for hemp wool in [Collet 2004].

The OSB shows the highest water vapor resistance factor as it shows much lowest porosity (60 %). It is widely impacted by the effect of moisture content on the water vapor transfer. The values are lower than the ones given by the producer, by 30 % for the dry point and by 70 % for the wet point. Between the dry point and the wet point, the vapor resistance factor is reduced by 25 % according to the producer while it is reduced by 68 % in this study. Such reduction is observed in the same magnitude for wood and plywood in French regulation [ThU 2017].

The water vapor resistance of CAVAC and CSB panels are intermediate between OSB and Biofib values. The ones of CAVAC panel are half the ones of CSB, in agreement with their porosities. These values are close to the ones found in bibliography for bio-aggregate based building materials: 15 for wood shaving concrete [Amziane 2013], from 5 to 12 for hemp concrete [Collet 2004, Evrard 2008; Walker 2014]. Actually, the mainly open high porosity of bio-aggregate based building material gives them high water vapor permeability (i.e. low water vapor diffusion resistance).

Tab. 24: Water vapor resistance factors at dry point (0-50 %RH) and at wet point (53-88 %RH) of studied materials

	CSB	OSB	Biofib	CAVAC
$\mu_{0\text{-}50}$	27.2	138.3	3.6	11.0
$\mu_{53\text{-}88}$	8.5	45.4	2.0	4.6

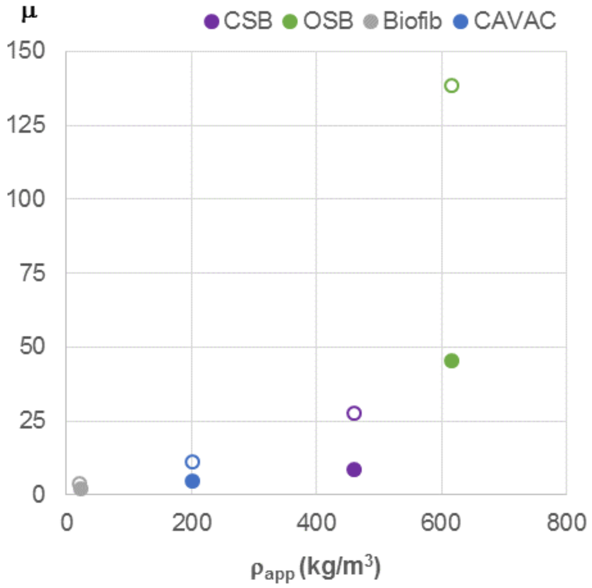

Fig. 72: Water vapor resistance factor versus density of studied materials – empty circle = dry point, full circle = wet point

4.4 Moisture Buffer Value

The Moisture Buffer Values of studied materials are given Tab. 25 and Fig. 73. The standard deviation between specimens is very low.

The MBV ranges from 0.53 g/(m^2.%RH) for OSB to 1.70 g/(m^2.%RH) for CAVAC panels. Following the classification of the Nordtest, OSB and CSB have a moderate capacity to buffer moisture variation while Biofib and CAVAC panel have a good one.

The comparison between studied materials is consistent with the results obtained for sorption isotherm and for water vapor permeability. Actually, the MBV is related to the moisture effusivity of the material, and thus, to the water vapor permeability (/ resistance factor) and to the sorption curve. So, Biofib allows high moisture penetration due to high water vapor permeability. CAVAC shows the highest MBV as it both allows moisture penetration (thanks to low water vapor resistance factor) and high moisture storage capacity. CSB shows lower MBV. Even if its moisture storage function is close to the one of CAVAC panel, its water vapor resistance factor is twice and induces a lower MBV. OSB shows the lowest MBV, in link with its high water vapor resistance factor.

Finally, on moisture buffering ability point of view, the CAVAC panels are the most interesting material to be placed on indoor side of the wall. Of course, once coated, their MBV can be reduced. The choice of coating is crucial to maintain good moisture buffering ability, or even increase it.

Tab. 25: Moisture Buffer Value of studied materials, average value and standard deviation

	CSB	OSB	Biofib	CAVAC
MBV_{abs} g/(m^2.%RH)°	0.75 ± 0.06	0.52 ± 0.01	1.34 ± 0.01	1.64 ± 0.04
MBV_{des} g/(m^2.%RH)°	0.79 ± 0.04	0.54 ± 0.01	1.34 ± 0.01	1.75 ± 0.03
MBV_{av} g/(m^2.%RH)°	0.77 ± 0.05	0.53 ± 0.01	1.34 ± 0.00	1.70 ± 0.04

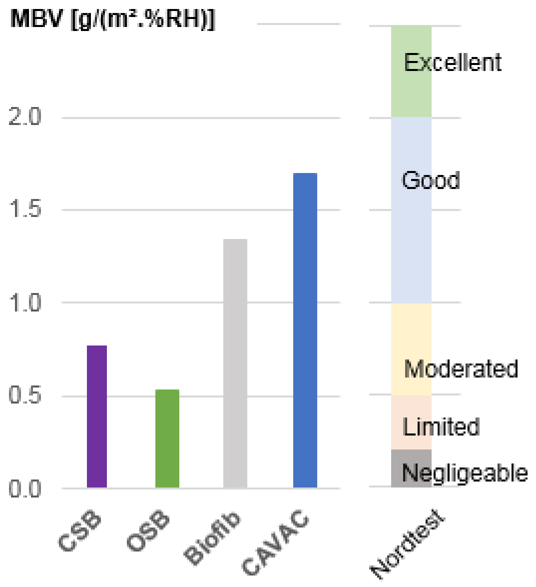

Fig. 73: Moisture Buffer Value of studied materials and MBV classification of Nordtest protocol [Rode 2005]

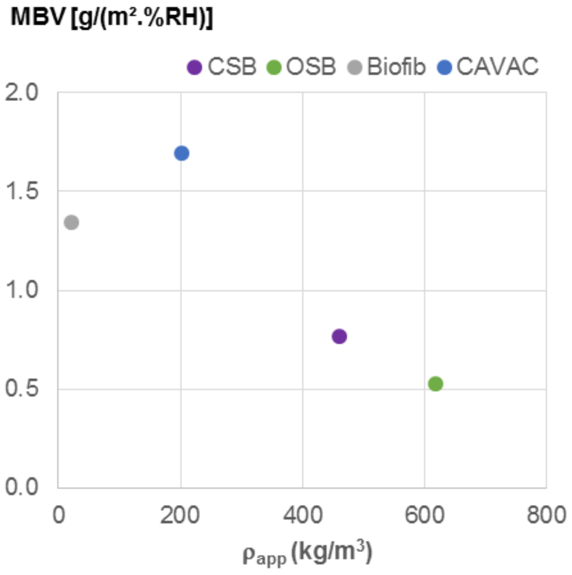

Fig. 74: MBV versus density

5 SUMMARY

The study provides an entire set of results that widely characterize the hygric behavior of studied materials and allow to compare them. The studied materials are hygroscopic. It is underlined that their kinetics of sorption are very different, such characteristic should be taken into account while modeling. On moisture transfer point of view, Biofib shows very low water vapor resistance factor while OSB shows very high and CSB and CAVAC medium. The MBV results are consistent with sorption and water vapor permeability ones. Actually, Biofib shows good ability to moderate moisture variation as it allows moisture to penetrate thanks to high permeability. CAVAC shows the best MBV as it both allows moisture transfer and storage. CSB shows lower MBV than CAVAC due to higher moisture transfer resistance. Finally OSB shows moderate ability due to very high moisture transfer resistance. More, to complete this study, further investigations are needed regarding the thermal performances, and namely the effect of humidity on them.

These data are useful to be implemented in numerical models that simulate hygrothermal behavior at wall scale. Such simulations will then be compared to experimental measurements made on the laboratory test-wall implemented in a bi-climatic chamber.

6 ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 636835 – The authors would like to thank them.

Thanks are due to Tony Hautecoeur for his participation to the measurements.

7 REFERENCES

[Amziane 2013] Amziane, S., Arnaud L. (eds.): Bio-aggregate-based Building Materials. Applications to Hemp Concrete. ISTE Ltd and Wiley, Inc 2013.

[Collet 2004] Collet, F., Caractérisation hydrique et thermique de matériaux de génie civil à faibles impacts environnementaux, Ph.D. thesis, INSA de Rennes, 2004.

[Colson 2017] Colson, V. ; Le Cunff, T. ; Jadeau, O.; Lanos, C.; Industrial scale-up of bio-based insulating panel production, in ICBBM, Clermont-Ferrand, France, 2017, e-ISBN: 978-2-35158-192-6.

[EN ISO 12571 2000] Norme Européenne EN ISO 12571, 2000, Performances hygrothermiques des matériaux et produits pour le bâtiment, Détermination des propriétés de sorption hygroscopique, ISBN 0335-3931.

[EN ISO 12572 2016] Hygrothermal performance of building materials and products - Determination of water vapour transmission properties - Cup method, 2016.

[Evrard 2008] Evrard, A., Transient hygrothermal behavior of Lime–Hemp materials, Ph.D. thesis, Université catholique de Louvain, 2008.

[Glassco 1987] Glassco, R. B. ; NOBLE, R. L., Modular building construction and method of building Assembly, 1987, http://www.google.fr/patents/WO1987003031A1.

[IUPAC 1986] International Union of Pure and Applied Chemistry, Reporting physisorption data for gas/solid systems with special reference to the determination of surface area and porosity, Pure and Applied Chemistry 57 (4) (1986) 603–619.

[Rode 2005] Rode, C.; Peuhkuri, R.H.; Mortensen, L. H.; Hansen, K. K; Time, B.; Gustavsen, A.; Ojanen, T.; Ahonen, J.; Svennberg, K.; Harderup, L.; Arfvidsson, J.; Moisture buffering of building materials, Technical University of Denmark, Department of Civil Engineering, 2005.

[ThU 2017] RT 2012 - Règles Th-Bat : Fascicule Matériaux, décembre 2017.

[Viel 2017] Viel, M.; Collet, F.; Lanos, C.; Thermal insulation materials from renewable resources: Thermal and hygric performances, in ICBBM, Clermont-Ferrand, France, 2017, e-ISBN: 978-2-35158-192-6.

[Viel 2018] Viel, M.; Collet, F.; Lanos, C.; Chemical and multi-physical characterization of agro-resources' by-product as a possible raw building material, Industrial Crops and Products, 2018, 120, 214–237. doi:10.1016/j.indcrop.2018.04.025.

[Walker 2014]. Walker, R., Pavía, S.: Moisture transfer and thermal properties of hemp–lime concretes. Constr. Build. Mater, 2014, 64, 270–276.